CARACTERIZAÇÃO EXPERIMENTAL DO COMPORTAMENTO DE ADERÊNCIA DE VARÕES COMPÓSITOS TÊXTEIS

EXPERIMENTAL CHARACTERIZATION OF THE BOND BEHAVIOUR OF TEXTILE BRAIDED COMPOSITE RODS

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RESUMO

Eventos sísmicos têm demonstrado a vulnerabilidade de paredes de enchimento inseridos em pórticos de betão armado, sendo importante avaliar técnicas de reforço que possam ser implementadas em paredes existentes ou em construção, a fim de melhorar o seu desempenho sísmico. O presente trabalho surge no âmbito de um estudo que apresenta uma adaptação sugestiva de materiais convencionais (FRP), utilizando varões compósitos entrançados (BCR), através de malhas aplicadas no reboco de paredes usando a técnica de argamassa reforçada com têxteis (TRM). O comportamento fora do plano da alvenaria pode ser melhorado, assegurando uma aderência adequada entre a argamassa e os materiais de reforço. Uma campanha experimental foi realizada com diferentes varões e com diferentes características de superfície através de ensaios de arrancamento. Assim, é possível seleccionar a melhor tipologia de estrutura fibrosa que pode ser aplicada nas paredes, apresentando um comportamento apropriado em termos de aderência, evitando o deslizamento e roturas frágeis.

ABSTRACT

Seismic events have been demonstrating the vulnerability of the infill walls inserted in reinforced concrete frames, being important to evaluate reinforcement techniques that can be implemented in existing walls or being built, in order to improve their seismic performance. The present work appears in scope of a study which provides a suggestive adaptation of the conventional materials (FRP) using a fibrous structure composed of braided composite rods (BCR), through of meshes applied on the rendering of the walls using the Textile Reinforced Mortar (TRM) technique. The out-of-plane behaviour of the masonry can be improved, but an adequate adhesion between mortar and reinforcing materials should be ensured. An experimental campaign was carried in different rods with different surface characteristics through pull-out tests. Thus, it's possible to select the best typology of rod that can be applied on walls, presenting a suitable behaviour in terms of adhesion, avoiding sliding and brittle failures.

1. INTRODUCTION

1.2 Background

The safety of the built spaces is indeed a demand of modern societies and remains a huge concern in seismic prone regions. It is known that seismic vulnerability is not exclusive of ancient masonry structures but affects also the built heritage from XX century, composed of a majority of reinforced concrete (RC) buildings, both in structural and non-structural elements (Lourenço, Vasconcelos et. al (2010)).

Despite masonry infill walls have been considered for long time as non-structural elements, they can play a positive role in the seismic behaviour of RC buildings, if their influence on the building response is correctly taken into account (Al-Chaar et. al (2002)). Conversely, they need to be checked against in-plane severe damage and possible out-of-plane collapse. Indeed, as demonstrated by recent earthquakes, the inefficient behaviour of masonry infills can result in extensive economic losses, resulting in low levels of reparability, and in the loss of human lives. During the action of horizontal forces, masonry walls have been demonstrating collapse mechanisms out of the plane, whose behaviour is characterized as brittle and so are modes undesirable because of the risk to human safety (Al Chaar, et. al (2002), Shing, P Benson (2002), Lourenço, et. al (2011))

Because of that, it raises the need for improvement of the construction technology and design of non-structural elements for new buildings and of retrofitting in case of existing buildings, taking into account that great part of RC buildings was designed before the advent of seismic regulations.

1.2 Seismic behaviour of masonry walls and its retrofitting techniques

Take into account the studies conducted by some author (P Benson Shing (2002), Varum, H et. al (2011), Lourenço, et. al (2011)) the behaviour of the walls depends on the resistance, stiffness and slenderness of the panel in interaction with the surrounding frame, complementing also the characteristics of the joints of the infill wall. The behaviour out of the plane walls infill is typically characterized by premature cracking of mortar in the joints. As the forces increase, the segments move out of the plane of the wall, the pillars slid in the frame, developing bows of bending, occurring to the total rupture of the wall panel (Fig. 1).

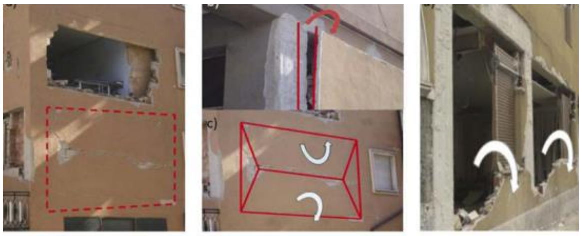


Fig. 1 – Out-of-plan collapse mechanisms of masonry walls (Oliveira (2009)

Thus, it is important evaluate reinforcement technique that can decrease the damage associated seismic events. This techniques may be varied, being the textile reinforced mortar (TRM) technique as an alternative of using laminated fibre reinforced polymer (FRP). Indeed, FRP technique has demonstrated some disadvantages regarding the bond with the masonry wall, due its detachment when subjected to bending, providing the loss its abilities due existing damage. On the other hand, TRM technique have demonstrated potential characteristics in terms of adhesion since it is possible to optimize the structure of surface of bonding. TRM technique have demonstrated also good performance in terms of the strength and deformation capacity with different reinforcement materials and comparatively other techniques (namely FRP), take into account the developed work by some authors.

Bending and shear behaviour of reinforced walls were studied by Papanicolaou et. al (2007, 2008, 2011), Triantafillou et. al (2007), ranging the numbers of layers the reinforcement applied in both side, typology of the reinforcement (glass mesh, carbon mesh, basalt mesh, propylene mesh and polyester mesh), typology of the bonding and the load level of compression applied in samples. Based on the response of masonry walls subjected to cyclic loading out-of-plan or loading plan, it is concluded that the overlapping TRM provide a high benefit in strength and particularly in the deformation capacity. In terms of deformability, TRM technique has been more effective than FRP (EBR), changing according to the type of wall geometric level (15-30% in shear walls up to 350% in the walls of the beam type). Furthermore, the strength generally increases with the number of layers and the axial load capability due to the deformation. With regard to the manner of collapse of the walls with reinforcements TRM, these depend on factors such as the relationship between the traction capacity of the reinforcement and compressive strength of masonry, bond strength reinforcing wall and the inside reinforcement.

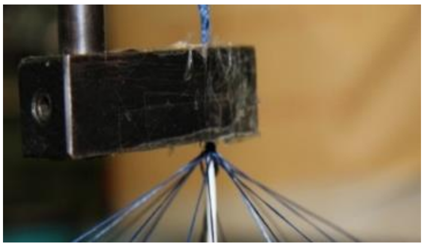
Rupika (2010) presents a work that studied the performance the different types of materials in retrofitting of infill walls. Steel meshes, glass, carbon and polypropylene fibre applied on configuration of meshes were embedded on the rendering of walls. Steel mesh applied on plastering masonry walls subjected to bending tests presented good behaviour in terms of maximum strength, although the observed deformation and ductility has not been so favourable, leading to brittle failure of the wall due to the low elasticity offered by strengthening. However, the study was also made of polymeric material and glass fibre mesh, showing a low bearing capacity for the remaining reinforcements, however they keep after opening cracks up high levels of deformation. On the other hand, a stiffer and more homogeneous behaviour is noticed when TRM is applied. The in-plane stiffness has proved to be highly dependent on the type of strengthening mortar whereas the out-of-plane stiffness is mainly defined by the type and amount of fibres (Bernat et. al (2013)).

Given this, the potential benefits of the infills walls reinforcement as way to prevent serious damage in case of seismic events, go beyond the mere stability of nonstructural elements, because it would improve the behaviour of the whole structure to face seismic events through of enhancement the ability the ductility in structure. This mechanism ensures a high level of confidence in reinforcing materials and it allows dissipate energy when subjected to cyclic loading, this behaviour is observed during an earthquake (Martins (2013) Martins et. al (2014)). In that case, through of the use of textile reinforcement mortar (TRM), some new structures based on braiding techniques have been developed in the last years in the University of Minho (Fangueiro (2011) Cunha (2012) Martins (2013)). The idea is to get composites rods through braided fibrous structures composed of an internal core of reinforcing fibres, such us glass or carbon and an external braided surface made by polyester or other textile fibres, being after its production combined in meshes in two perpendicular directions. Besides the percentage of the reinforcing materials in the internal core of the braided structure, it is important to evaluate the most appropriate spacing of the structures in the mesh, which reveals to have a great importance in the improvement of the flexural behaviour of brick masonry (Martins (2013), Gómez (2012)). 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 and low-cost procedures for its production. Moreover, the shape of the rod can be designed in purpose of the performance in terms of adherence, in order to get the best bonding with involved mortar (Cunha (2012), Cunha, et. al (2013)). So that, an experimental campaign was developed in order to analyse the mechanical behaviour of different external bonding surfaces when are pulled out inside of mortar of plastering. Thus, it can possible to evaluate and optimize its characteristics in order to select the best configuration of external surface in order to be applied on meshes of reinforcement of masonry walls. Moreover, meshes constituted with these optimized rods were tested in terms of adherence through of pull out tests considering representative samples of masonry.

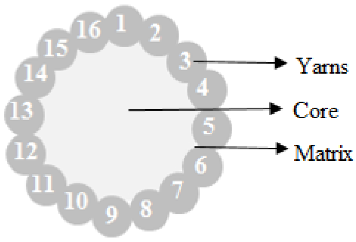
2. ADHERENCE TESTS IN INDIVIDUAL RODS

2.1 Braided composite rods – BCR

The reinforcement material is designed by the braided composite rods, BCR and it is result of a process designed by braiding simple. This technique for producing braided fabrics is usually used for the manufacturing of fibrous reinforcements for construction applications (Fangueiro (2011)). It has been used for two centuries and is being increasingly used for technical applications. This technology consists on a combination of three material types, each with different functions. Thus, this technique involves braiding in the transverse and longitudinal directions forming a tubular structure. The yarns that make up the base of the braid, involve a central core responsible for the mechanical performance. The yarns are in two groups of spindles and rotate in opposite directions, clock and counter- clock wise (Fangueiro (2011)). With the aim of improving mechanical properties and for adding new functionalities, axial fibres are added (Fig. 2 (a)). In Fig. 2(b) the representative scheme of resultant transversal section of BCR can be observed.



(a)



(b)

Fig. 2 - (a) Production and (b) Schematic representation of the simple rod without roughness

This structure can be composed of different materials and different configuration of yarns, causing different roughness of external surface in order to achieve optimized mechanical behaviour in terms of adhesion.

On the other hand, in order to fill the voids between the materials providing stability and homogeneity of the composite is applied a resin matrix. In fact, the success of material depends largely on the performance of the core, because the acting loads are absorbed by core of rod, which allows improving the performance of masonry walls. It is then necessary that the type of material applied is chemically stable and has appropriate characteristics in terms of tensile strength and in terms of density, since the core is that has higher percentage of material. In addition, the material cost is also an important factor, which is crucial for the proper management of the economic value combined with the mechanical capabilities of each type of fibre, in order to obtain products which satisfy the requirements suitable mechanics with priced competitive.

Braiding angle is the most important parameter in characterizing a textile braided structure, influencing directly its mechanical behaviour. Braiding angle is the angle between the longitudinal axis and the direction of insertion of the braiding yarns, as can be seen in Fig. 3. The diameter of the braid is the straight line connecting the two extremities passing through the braiding centre (see Fig. 3). This measure can vary according to the braiding yarn diameter, diameter of the axial structures and circulation velocity (Fangueiro (2011)).

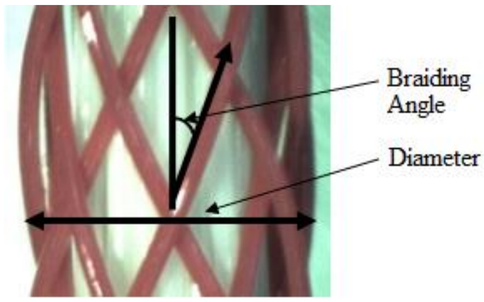


Fig. 3 – Braiding angle and diameter of BCR (Cunha (2012))

To better understand the behaviour of rods uniaxial tensile tests based on NP EN ISO 2062 and ASTM 5034 in rods were developed. These rods are constituted with glass and carbon fibres in its core because this fibre were used in meshes applied on plastering of masonry walls. Thus, through the obtained results, it is possible to conclude that the core reinforcement is responsible for BCR initial stiffness and maximum load achieved. Due this, the initial stiffness and maximum force of carbon rods is more accentuated than stiffness of rod of glass.

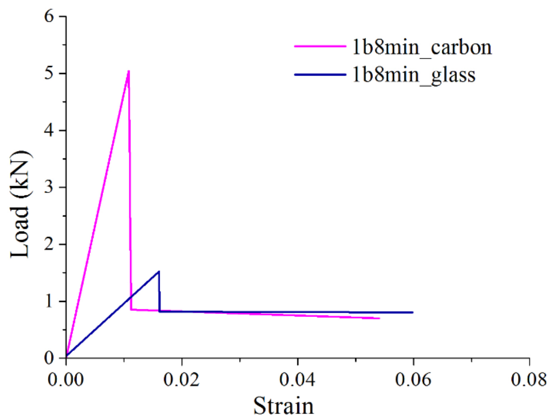


Fig. 4 - Typical response of load-strain of each typology of composite rods

The Fig. 4 sows the typical behaviour of each type of fibre, being possible to see the difference before the value peak, and the similarity after rupture of resistance fibres. At the time of rupture, the polyester is totally loaded, which justifies the existence of a ductile plateau due to high elasticity of the composite common in both types of rods tested.

2.2 Preparation of specimens

The experimental assessment of the influence of the surface tailoring of braided structures on the adhesion with mortar was carried by carrying out simple tensile bond tests (pull-out test). Using different rods with different characteristics on its external surface, different roughness were obtained by replacing polyester multifilament (1 or 2) by braided simple structure (roughness), composed of 8 or 16 polyester yarns produced with different speeds, resulting a total of 14 types of structure of braided. The name of each type of structure of braid and its description according Fig. 2 (b) are described in Table 1. The core of all rods are constituted by two multifilament of carbon 1600 Tex, not allowing the rupture through of reinforcement core, but causing the rupture by adherence between materials.

For each type of structure of braided, 5 tests of adherence were made to understand the behaviour of the different structure of the braid when it is pulled out inside mortar. Therefore the structure with the best behaviour can be chosen in order to be applied in the reinforcement of infill walls.

Table 1 - Definition of the samples for flexural **tests**

Sample Designation	Description of the samples	Speed (m/min)
0bmin	**1** to **16** multifilament polyester with 11 tex	0.54
0bmax		1.07
1b8max	**1**- Braided multifilament consisting of 8 Polyester 11 tex **2 to 16**- multifilament polyester with 11 tex	1.07
1b8int		0.8
1b8min		0.54
2b8max	**1** and **9** - Braided multifilament consisting of 8 Polyester 11 tex **2 to 8 e 10 to 16** - multifilament polyester with 11 tex	1.07
2b8int		0.8
2b8min		0.54
1b16max	**1** - Braided multifilament consisting of 16 Polyester 11 tex **2 a 16**- multifilament polyester with 11 tex	1.07
1b16int		0.8
1b16min		0.54
2b16max	**1** and **9** - Braided multifilament consisting of 16 Polyester 11 tex **2 to 8 e 10 to 16** - multifilament polyester with 11 tex	1.07
2b16int		0.8
2b16min		0.54

For this purpose, cylindrical specimens of mortar were developed with the rods inside them to be pull out in 2 series in order to understand the influence of resistance of mortar in pull out of rods.

The mortars used in the specimens are pre-mixed mortar comprising cement, lime, calcareous aggregates and chemical additives and needs only water to be mixed before use. The mortar paste has a density of 1750 ± 200 kg/m3 and consistency of 150 ± 10 mm. The preparation of the mortar specimens was carried out according to NP EN 196-1 (2006) standard. The tests were carried out after 28 days of curing of the mortar specimens. The difference between the series is the strength of mortar because the mortar used in series 2 is stronger 77% in terms of resistance of compression (series 1 - 2,01 MPa and series 2 - 3,56 MPa) and 33% regarding to resistance of flexion than the mortar used in series 1 (series 1 – 1,21 MPa and series 2 – 1,61 MPa), and it was used in construction of masonry specimens.

Fig. 5 - Production of specimens for tests pull out

The specimens presented a diameter with 50 mm and 100mm of length and they were kept in conditions of laboratory for 28 days. The rods were introduced inside in centre of sample in all its length in moment of the its manufacture. On the tip of the rod, a bond was created that it allow the connection and fastening of rod at machine that pulls the rod of inside of the specimens of mortar (Fig. 5).

2.3 Test setup

The test procedure for the study of adhesion of composite rods in cylindrical specimens was based on the work previously carried out by different authors, including Cunha (2012), Martinelli et al. (2011), Baena et al., (2009) and Kashyapa et al. (2012).

The adherence test was developed on a portico sufficiently rigid associated with a system control and data acquisition linked to a computer system that allows the registration of the applied loads and displacements suffered by the samples. The vertical tensile load is applied through a hydraulic actuator and measured by a load transducer of the additional load of 10 kN, and the deformation was measured through a device designated by Linear Variable Differential Transducer (LVDT). This device measures the linear sliding of the rod out of the sample.

The cylindrical specimen of mortar is confined vertically through of two steel sheets previously rectified and connected together, in order to promote the relative displacement between the rod and the specimen of mortar (Fig. 6). The test speed was 0,010 mm/s which corresponds to the test duration of approximately 45 to 60 min, suitable for this kind of tests.

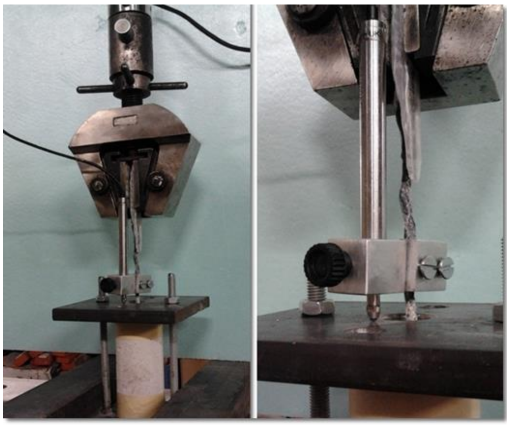


Fig. 6 - Test setup

2.4 Results

The obtained results can be observed in Fig. 7 and Fig. 8 in terms of diagrams force vs deflection and in relation to maximum load of each type of rod, respectively. It is possible to conclude that:

- The roughness formed by a simple braid with 8 yarns exhibit a behaviour more satisfactory than the roughness with 16 yarns in terms of load-displacement diagrams, because they presented a better ductile behaviour and adherence forces. The factors that influences the maximum adhesion force depend on the interaction of the adherence area of the rods and the effect of interlocking controlled by roughness. Regarding the behaviour of rod, it is possible to conclude that the less resistant mortar leads to lower values, which is also reflected in the more ductile post-peak behaviour. On the other hand, in terms of confinement greater amount of mortar gives higher values of adhesion.
- The most satisfactory performance in terms of maximum force recorded is was observed on structure called 1b8max. However, it was found by the manufacture of the rods to be applied on the walls, it was not feasible to use this roughness because of the lack of homogeneity of the finished braid, since

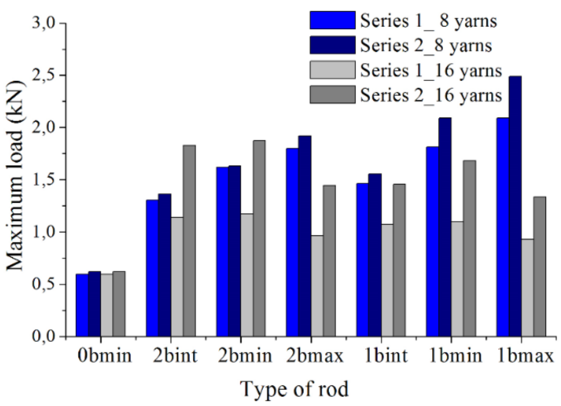


Fig. 7 - Maximum load for each type of rod

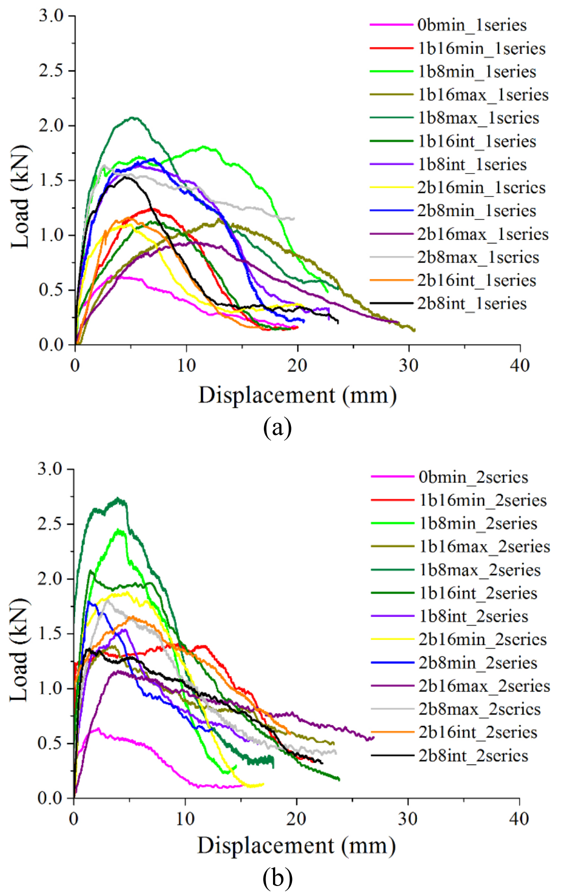


Fig. 8 - Obtained results in (a) series 1 and (b) series 2

it was necessary to increase the amount of material in the core. It can also be concluded that the manufacture of the rods from the braiding technique with existing conditions may depend on the diameter of the reinforcement to be included in the core. Therefore, the alternative braided structure selected for rod was 1b8min, consisting of 15 multifilament polyester 11 Tex and 1 element of braided simple structure consisting of 8 braided polyester yarn with minimum speed of the production equipment (0.54 m/min). Therefore, the braided protect the core totally because the minimum speed allows better involvement of the core. Thus, the selected BCR rod has a helical ledge which increases the bonding to the mortar through the engaging its shape.

3 AHERENCE TESTS IN REPRESENTATIVE MESHES OF REINFORCEMENT

3.1 Meshes of reinforcement

Representative meshes were developed with selected braid structure, in order to understand the behaviour of a set of rods when are pulled out inside plastering of mortar on masonry samples. The rods are constituted by two multifilament of carbon 1600 Tex as in tests in cylindrical samples, and the selected braid structure was 1b8min, taking into account the production of reinforcement to be applied on masonry walls. Besides this braid structure, the original configuration without roughness (0bmin) was also considered in order to analyse the influence of roughness in adherence to mortar.

The manufacture of the meshes is made by interlacing the rods in two directions. The configuration of the connections of rods leads to some roughness of the mesh, which can results in an additional imbrication (Fig. 9).

Beyond the study of the meshes constituted by braided composite rods, two commercial solutions with similar mechanical and physical characteristics were tested in order to get the viability of produced meshes. These meshes

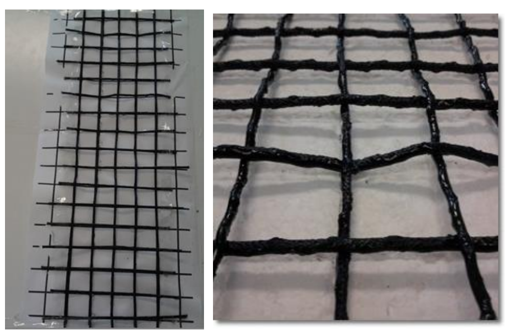


Fig. 9 – Details of mesh

are different in terms of type of fibers, being the Comm_carb constituted by carbon fiber in main direction and Comm_glass constituted by glass fibers. The Comm_carb is unidirectional, taking into account that carbon fibers are oriented in the direction where bending develops, whose density is 200 g/m with spacing of approximately 25mm the main direction. Based on the technical information, the mesh has a flexural strength of 93.6 kN/m for an extension at maximum stress of 1.75 %. The commercial mesh of glass fibers (Comm_glass) consists of resistant glass fibers in both directions. Once bidirectional, the mesh density is $225g/m^2$ with spacing between the fibers of 25mm. From the technical information, it is seen that the flexural strength is 45 kN/m with associated extension at break less than or equal to 3%.

Because of theses meshes present the spacing of 25mm, manufactured meshes were developed with same spacing in order to minimize difference between them.

3.2 Preparation of specimens

The construction of representative masonry specimens was made by an experienced mason in order to reproduce similar workmanship used in current structures. The samples were kept under relatively stable conditions of temperature and humidity inside the laboratory (Fig. 10). This was made by applying a thin layer of mortar, with subsequent placement of the reinforcing mesh embedded in a new layer of rendering mortar, giving a total thickness of about 20mm. The mortar used in this tests was used in series 2 of individual rods tests and in construction of masonry walls.

The dimension of inserted mesh in plastering was (length x width) 200 mm x 100 mm, presenting the same free area on sample. On the tip of the each mesh applied on sample, a bond was created that it allow the connection and fastening of mesh at machine, as was created in individual rods.

For each typology of mesh, 5 tests were considered taking into account the viability of obtained results.

Fig. 10 – Application of meshes on masonry samples

3.3 Test setup

The test setup was based on configuration of individual tests of rods, as Fig. 11 sows. The tensile load was applied through hydraulic actuator and measured by a cell of the additional load of 200 kN. These tests were controled by displacement and the measurements were done by internal system. The speed test was 0.08 mm/s.

The support used fixed of sample brick, which allows only the measurement of displacements the mesh embedded in the mortar in relation at specimen. For this, the specimen was fixed to the base of the portico through plates and metal bars to prevent vertical displacements and rotations.

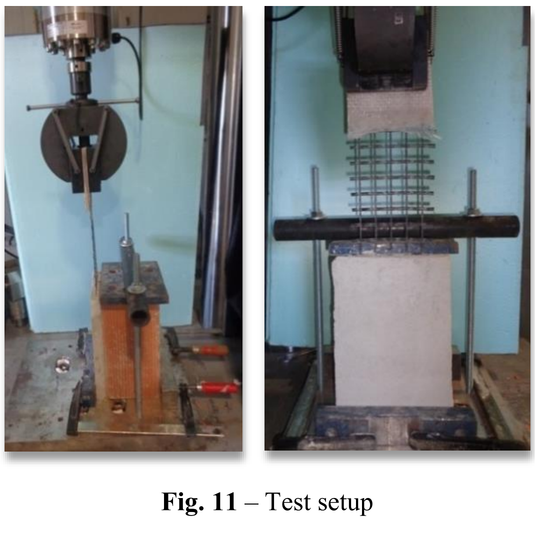


Fig. 11 – Test setup

3.4 Results

The results can be analysed in Fig. 12. Indeed, the results depend of behaviour of samples during tests, because as occur in tests of individual rods, it is necessary that the rods does not slid of rod in bonding with machine.

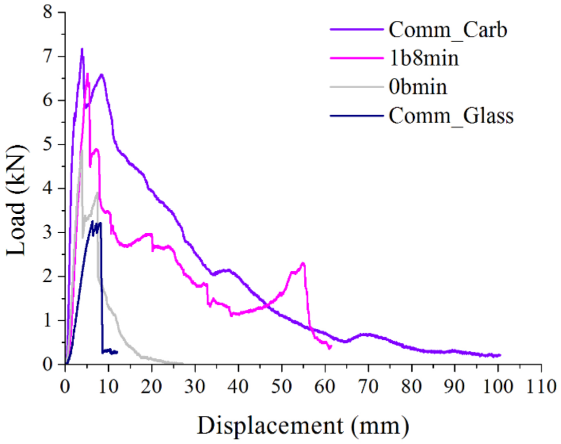


Fig. 12 - Load-deflection response of the meshes

The behaviour of mesh with 1b8min rods presented very similar behaviour in relation to correspondent commercial solution with carbon fibers. The maximum force was almost the same, but more important than that, the behaviour post-peak was very ductile and through these results it is possible to validate the behaviour of produced mesh in terms of adherence. A ductility in this material is more important than the maximum force, because in scope of its application, it is important that the masonry wall can present high deformation with security before the total damage occur, avoiding sliding and brittle failures.

The mesh constituted with rods without roughness presented a fragile behaviour. These meshes presented a transverse and longitudinal interlacing of rods, providing the locking of the mesh when it was pulled out. Although both meshes (1b8min and 0bmin) was this characteristic, this effect is more relevant for 1b8min mesh due to the additional roughness that each rod has, functioning as a friction agent that promotes the adhesion.

On the other hand, the behaviour of the commercial solution with glass fibre presented a fragile behaviour since the meshes presented total damage before this had been pulled out inside mortar.

The pattern of rupture of the produced meshes presented the formation of multiple cracks associated with the effect of the distribution of forces, sometimes presenting also the fragmentation and detachment of the mortar in any area of the plastering, whereas the commercial carbon clearly showed one crack whereby the mesh slid when it was pulled (Fig. 13). This difference can be associated also with the global interlocking that the produced meshes have due the interlacing of rods, aspects not visible in very plane commercial mesh.

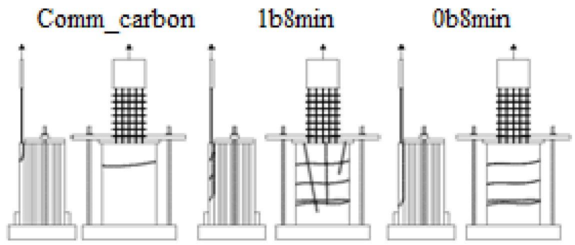


Fig. 13 – Failure scheme typical of pattern cracks

4 CONCLUSIONS

Regarding the study of adherence, the following conclusions are enumerated:

- The selected typology of braid structure to applied in reinforcement of masonry walls was 1b8min, consisting of 15 multifilament polyester 11 Tex and 1 element of braided simple structure consisting of 8 braided polyester yarn and 2 multifilament of carbon, produced with minimum speed of the production equipment (0.54 m/min).
- The less resistant mortar leads to values lower pull out, which is also reflected in the more ductile post-peak behaviour.
- The factors that influences the adhesion force are related with the interaction of the adherence area of the rods and the effect of interlocking controlled by roughness.
- The interlacing of the longitudinal and transverse rods of the meshes function as an additional roughness that promotes adhesion of the mortar mesh. Therefore, there are higher redistribution of forces and formation of multiple cracks, which provide the detachment and disaggregation of the outer mortar in any areas.
- Commercial meshes with carbon fibres presented a similar behaviour compared with produced meshes with roughness, which ensures the viability of these meshes composed with braided composite rods.

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