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Experimental assessment of an innovative strengthening material for brick masonry infills

A. Martins [a, 1], G. Vasconcelos [a, *], R. Fangueiro [b, 1], F. Cunha [b, 1]

[a] ISISE, Department of Civil Engineering, University of Minho, Azurém, P-4800-058 Guimarães, Portugal
[b] 2C2T, Department of Civil Engineering, University of Minho, Azurém, P-4800-058 Guimarães, Portugal

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ABSTRACT

The vulnerability of masonry infill walls has been highlighted in recent earthquakes in which severe in-plane damage and out-of-plane collapse developed, justifying the investment in the proposal of strengthening solutions aiming to improve the seismic performance of these construction elements. Therefore, this work presents an innovative strengthening solution to be applied in masonry infill walls, in order to avoid brittle failure and thus minimize the material damage and human losses. The textile-reinforced mortar technique (TRM) has been shown to improve the out-of-plane resistance of masonry and to enhance its ductility, and here an innovative reinforcing mesh composed of braided composite rods is proposed. The external part of the rod is composed of braided polyester whose structure is defined so that the bond adherence with mortar is optimized. The mechanical performance of the strengthening technique to improve the out-of-plane behaviour of brick masonry is assessed based on experimental bending tests. Additionally, a comparison of the mechanical behaviour of the proposed meshes with commercial meshes is provided. The idea is that the proposed meshes are efficient in avoiding brittle collapse and premature disintegration of brick masonry during seismic events.

1. Introduction

Several past seismic events in southern Europe have highlighted the vulnerability of the very common constructive solution of enclosure brick masonry walls. This construction element is very common in reinforced concrete buildings and also in steel buildings [1]. The masonry infills present out-of-plane failure mechanisms, which are characterized as being brittle and thus considered as undesirable due to the high cost involved in repair/reconstruction and to the risk to human safety [2–4]. Generally, the behaviour of the walls depends on the resistance, stiffness and slenderness of the panel and its interaction with the surrounding frame. For decades, these elements have been considered as nonstructural and therefore there are no specific guidelines for their design [2]. Besides, the constructive details in the daily design of buildings are almost non-existent. In this respect, Eurocode 8 (2004) [5] provides some recommendations about the construction of masonry infill walls to improve their in-plane and out-of-plane behaviour and to avoid their brittle failure and premature disintegration, including: (1) the addition of light wire meshes well anchored on one face of the wall; (2) wall ties fixed to the columns and cast into the bedding planes of the masonry; (3) concrete posts and belts across the panels and through the full thickness of the wall.

This means that there is a large segment within the building stock in seismic-prone areas that needs to undergo preventive actions, particularly for out-of-plane loads. This can range from simple connection of the masonry infills to the frame structures, which can also be applied to the case of already damaged elements, to the strengthening of the masonry infills. The potential benefits of strengthening the masonry infills go beyond the stability of these nonstructural elements, as this can improve also the behaviour of the whole structure when faced with seismic events [6].

The strengthening solutions for masonry infill walls may be varied and there has been an evolution with respect to methods and materials. Laminated fibre-reinforced polymer (FRP) strengthening is a viable retrofitting technique due to its small thickness, advantageous strength/weight ratio, high stiffness, and because it is relatively easy to apply. This material was firstly applied in concrete structures by bonding external polymer sheet to the surface (EBR technique) or by introducing the laminated fibres into slots (near surface-mounted technique) in the concrete [7]. However, these

* Corresponding author. Tel.: +351 253 510 200; fax: +351 253 510 217.
E-mail address: graca@civil.uminho.pt (G. Vasconcelos).
[1] Tel.: +351 253 510 200; fax: +351 253 510 217.

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materials also have disadvantages like inadequate bonding of the reinforcement to the masonry, resulting often in the detachment of the reinforcement relative to the support. An alternative retrofitting technique that has been studied is based on meshes of fibres embedded in cementitious matrix materials, commonly referred to as Textile-Reinforced Mortar (TRM). This technique may provide several advantages such as the overcoming of bond weakness and problems with humidity [8]. In this respect, optimization of the textile meshes inserted in masonry mortar with the aim of improving the tensile strength of the walls and the deformation capacity, resulting in a more ductile failure, has been investigated [8,9]. Several authors [10–17] have analysed the bending and shear behaviour of strengthened masonry walls, varying the number of layers of the reinforcing materials applied in both sides, the typology of the reinforcement (glass mesh, carbon mesh, basalt mesh, propylene mesh and polyester mesh), alternative bonding materials like epoxy resin, and the load level of compression applied in the samples. Based on the response of masonry walls subjected to cyclic out-of-plane loading, it was concluded that the TRM technique results in great benefit to the strength and particularly to the deformation capacity. This enhanced mechanical behaviour under flexure is attributed to the tensile resistance of the reinforced mortar, the failure being controlled by failure of the fibre or by sliding of the mesh or fibres from the mortar. Even weak TRM solutions ("low-tech" textiles combined with low resistance), when properly placed, result in a major increase in the resistance and deformation capacity in walls submitted to out-of-plane loading compared to walls reinforced with FRP. In the case of in-plane behaviour, the TRM technique results also in a positive effect on the resistance of about 65–70% compared with the FRP layers of identical configuration [11]. In terms of deformability, TRM was revealed to be more effective than FRP, but the efficiency varies greatly according to the type of wall and geometry (15–30% higher deformation in shear walls and up to 350% higher deformation in beam type walls) [9]. Furthermore, the strength generally increases with the number of layers and also depends greatly on the type of mortar [12–14]. Rupika (2010) [18] presented a work pointing out the performance of the different types of retrofitting on masonry infill walls. As reinforcing materials, steel meshes, glass fibre and polypropylene fibre mesh embedded in the mortar were considered. The steel mesh applied in plastering masonry walls subjected to bending tests revealed advantages in terms of maximum strength, although the observed deformation and ductility were not improved. The laminated polypropylene showed a low bearing capacity in relation to the other reinforcements but kept working after the opening of cracks led to high levels of deformation. The fibreglass meshes provided a high strength corresponding to the breakage of the fibres.

Bernat et al. (2013) [19] carried out a study based on the strengthening of masonry walls with the TRM technique with the purpose of understanding the influence of three different types of mortar, two different types of fibre (glass and carbon grids) and the possible benefit of using anchors to improve the connection between the walls and the external reinforcement. For this, an experimental campaign on real-size TRM strengthened masonry walls under eccentric compressive loads was carried out. It was observed that all the mortars reached the necessary bond strength to assure the adherence of the TRM to the masonry, so that no connectors seemed necessary in the strengthening of walls under eccentric compressive loads. Indeed, the application of TRM has provided an increase of over 100% of the initial load-bearing capacity under eccentric axial load. Moreover, 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.

Another aspect investigated was the technique of application of mortar (TRM), namely manually and sprayed mortar (TRSM) [20]. Different mortars and fibre grids achieved by using both types of application techniques were analysed. It was possible to conclude that there was a notable increase in productivity (between 2 and 6 times more) with TRSM, and it was also possible to obtain an enhanced resistance. Moreover, greater ductility values were also observed when TRSM is used in comparison with the TRM (same grid and mortar).

With respect to analytical modelling of composite materials used in the strengthening, namely layered materials and fibre reinforced material, homogenization techniques can be used to derive the mechanical properties [21,22]. In this respect, it is important to mention that the accurate prediction of macroscopic material properties of such materials on the basis of their microscopic mechanical behaviour is crucial for an efficient utilization of composite materials to engineering structures [21]. Additional theoretical studies have been also carried out in the definition of analytical solutions for functionally graded materials, which can be applied to composite structures [23–28].

Following the use of textile reinforcement mortar (TRM) as a retrofitting technique for masonry infill walls, some new textile fibre based materials manufactured through braiding techniques have been developed in the last years at the University of Minho, as an alternative to conventional FRP rods [8,11,29,30]. This material, called braided composite rods (BCR), which can be assembled as strengthening meshes, has some advantages such as the possibility of designing the composition according to mechanical requirements, the low manufacturing technology and the low-cost production. Moreover, the shape of the external surface can be optimized to improve the bond strength. Therefore, the main purpose of this paper is to provide the results on the mechanical performance of this novel material on the strengthening of brick masonry walls. For this, a detailed description of the strengthening, the manufacturing process and the results on the optimization of the surface of the rods based on tensile bond strength tests are provided. Additionally, the experimental campaign carried out on the evaluation of the performance of the braided rod meshes in the strengthening of brick masonry under flexure is presented and the main results are discussed. The performance of these meshes is also compared with the performance of different commercial meshes available in the market.

2. Description and mechanical characterization of braided composite rods (BCRs)

The strengthening material is designated as braided composite rod (BCR) and it results from a braiding process. This technique used for producing braided structures can be used for the manufacturing of fibrous reinforcements for construction applications [30,20]. It has been used for two decades and it is being increasingly used for technical applications. The braided structure consists of a combination of three types of materials, each one with different functions. The braiding technique involves the braiding of yarns in the transverse and longitudinal directions, forming a tubular structure. These yarns are in two groups of spindles and rotate in opposite directions, clockwise and counter-clockwise [30]. With the aim of improving the mechanical properties and for adding new functionalities, axial fibres are added in the core of the rod (see Fig. 1a). The yarns that make up the base of the braid then involve a central core composed of reinforcing fibres that are responsible for the mechanical performance. In Fig. 1b the representative scheme of the original transversal section of a BCR can be observed, having 16 multifilaments of polyester and a core filled with multifilaments of reinforcing fibres. In order to fill the voids