Construction and Building Materials 191 (2018) 228–241

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Mechanical properties of pre-stressed fabric-reinforced cementitious matrix composite (PFRCM)

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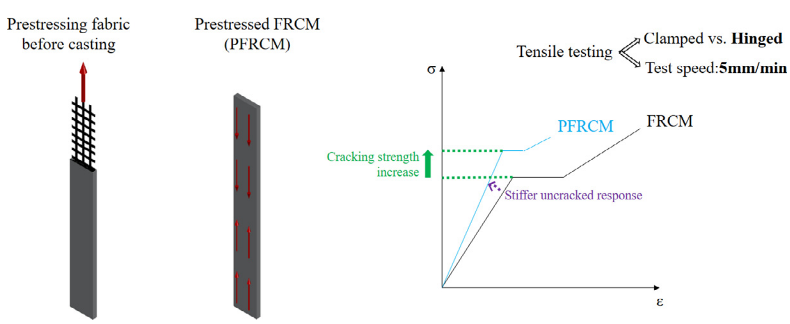
HIGHLIGHTS

- Prestressing fabric of FRCM increases its cracking strength over 30%.
- Prestressing fabric of FRCM promotes fabric sliding failure.
- Prestressing fabric of FRCM reduces tensile strength for fibre breaking failure.
- Tensile FRCM failure mode depends on fixation system.
- It is recommended to conduct tensile tests of FRCM at 5 mm/min.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 26 June 2018
Received in revised form 27 September 2018
Accepted 30 September 2018

Keywords:
FRCM
Pre-stressing
Experimental
Tensile test
Clevis

ABSTRACT

Fabric Reinforced Cementitious Matrix (FRCM) is a composite strengthening material used to strengthen masonry and concrete structures in a passive way due to the requirement of crack activation. Prestressing fabric is proposed to overcome this limitation, to increase the cracking strength and to obtain a stiffer response. With this aim, over 200 tensile tests on FRCM specimens were performed to analyse the influence of prestressing fabrics. Other variables, like fixation system, testing speed, matrix material and fabric material, were also discussed. Evidences lead to conclude that prestressing fabric of FRCM is an effective way to increase its tensile cracking strength (over 30%) and tensile stiffness.

1. Introduction

Fabric Reinforced Cementitious Matrix (FRCM), also called Textile Reinforced Mortar (TRM) among other nomenclatures, is an inorganic matrix composite material initially developed with the aim of strengthening concrete and masonry building structures. Most of the authors (see [1]) reported the outstanding performance of this composite material at strengthening those structures, which generally increase their ultimate strength and ultimate deformation. However, the passive nature of FRCM makes it necessary to crack the mortar matrix in order to reach the full contribution of the textile reinforcement. In addition, this fact causes large deformations of strengthened structures, which might set the design limits into the serviceability field instead than into the ultimate strength field. Thus, it is though that assuring the collaborative contribution of fibre and matrix from the very beginning of the loading process is essential to avoid the early matrix cracking and to increase the stiffness of the strengthened structure.

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https://doi.org/10.1016/j.conbuildmat.2018.09.210
0950-0618/

In this line, the research presented herein wants to do a step forward on the improvement of this composite material by prestressing the fabric. It is a promising approach to fulfil the particular aim of guaranteeing the full mechanical collaboration between the two components of the FRCM and limiting the deformation of strengthened structures. Increasing the cracking load will contribute to enhance the durability of the strengthened element, whereas increasing the stiffness of FRCM will make it even more suitable for strengthening concrete structures because of improved mechanical compatibility. In addition, prestressing fabric would open the door to effectively precast thin FRCM elements with applications far beyond strengthening. Nevertheless, in-situ application of prestressed FRCM and the description of the required tools and methods are out of the scope of the current paper, which is focused to the experimental characterisation of this composite material in the case of prestressing the fabric.

Nevertheless, the idea of prestressing continuous fibres embedded into a cementitious matrix is not completely new for author's knowledge. According to our records it was firstly proposed in 2001 by Krüger et al. [2] who analysed the influence of prestressing carbon and aramid rowings embedded into cementitious matrixes on the pull-out strength. They also analysed the effect of coating fibres with epoxy resins to enhance bonding strength. A few years after, in 2007, Xu and Li [3] presented a study that analysed the influence of several parameters on the fibre-matrix bond strength assessed using pull-out tests. One of these parameters was the fibre prestressing. The same year, the research conducted by Peled [4] studied the influence of low-tension (~7MPa) prestressed fabrics embedded into cement paste matrix by means of flexural tests, pull-out tests and SEM observations combined with viscous-elastic tests of fabrics to conclude that stiffer fabrics with reduced creeping are the ones which further improve cracking performance of cement composites.

Recently, Gopinath et al. [5] studied the influence of stretching fabrics on the tensile response of glass fibre FRCM specimens tested in clamped configuration. They concluded that mechanical stretching (0.15% elongation) contributed to enhance first cracking load and led to prevent sliding failure.

Thus, as far as we know, the tensile response of prestressed fabric reinforced cementitious matrix (called PFRCM from now and on) has been little studied and most of the existing researches are focused on analysing the bonding properties of prestressed fibres. Hence, the main aim of this research is to analyse the performance of PFRCM specimens in order to confirm the hypothesis that prestressing fibres would contribute to increase the cracking strength and the elastic modulus prior to cracking. To do so, production procedures for PFRCM specimens were defined and are reported with detail.

However, this novel research line required implementing tensile tests on FRCM specimens, which were no really standardised. Despite the numerous research contributions carried out in the recent years on FRCM and its use (see the review by Awani et al. [1]), there is no agreement on the testing configuration yet. In this line, the research by de Felice et al. [6] summarised several testing procedures implemented by different researchers. This situation leads to difficulties on comparing results from different materials or different testing setups, although the macroscopic response associated with different failure modes (early fibre breaking, core filaments slippage and sleeve filaments slippage) has been previously discussed (see [7]).

A clear example is the diversity of specimens' sizes and shapes: $400 \times 40 \times 10\ mm^3$, $600 \times 100 \times 10\ mm^3$, $410 \times 50 \times 10\ mm^3$, $600 \times 50 \times 10\ mm^3$ and $400 \times 32 \times 6\ mm^3$ where respectively used by Carozzi and Poggi [8], Larriñaga et al. [9], Arboleda et al. [10], De Santis and De Felice [11] and Escrig [12]. Furthermore, some authors used bone-shape specimens (e.g. Raupach et al. [13]) increasing the diversity of specimen's geometric definition. A brief summary of used shapes can be found in Hartig et al. [14], who reported the influence of the shape on the position of the cracking area.

In the same line, a remarkable diversity of fixation systems of the specimens to the testing machine have been proposed. Among them, direct clamping (see [8,12,15]) and Clevis fixation (see [16]) are the most common ones. Other possibilities are soft clamping [17] or using hinged steel flanges [13]. The influence of the fixation system has been widely studied (see [10,11]) concluding that clamped systems provide more stable response and greater load bearing capacity whereas the matrix-fibre sliding process can only be assessed using tangential load transmitting systems like Clevis one. This influence of the fixation systems on the failure mode was also studied by Carozzi and Poggi [8].

Regarding the test execution, different testing deformation ratios have been used (see [8,10]), mostly ranging from 0.1 mm/min to 0.5 mm/min but also changing the test speed depending on the testing phase (before or after crack development). It is commonly recommended to perform tests at 0.2 mm/min according with AC434 [18] although little literature is available about the influence of this parameter. In addition, there is also an ongoing discussion about the methodology to measure the strains on specimens. On this topic, Escrig [12] proposed using strain gages but the cracking process affected the measurements. Larriñaga proposed using 210 mm extensometer [19], which agrees with the proposals of Arboleda et al. [10] and Contamine et al. [20] of using the largest possible extensometers and placing up to four sensors if possible to take into account the likely bending effects during tensile testing.

Thus, a secondary aim of the current research was analysing the influence of testing speed and specimen fixation on the mechanical response of different FRCM systems (varying mortar and fabric beyond typical commercial prescribed combinations to wider research limits) in a comprehensive way to support the definition of the most suitable testing procedure for FRCM and PFRCM tensile characterisation.

2. Materials and methods

2.1. Mortar

Two different mortars were used to produce (P) FRCM specimens. The first one (*S*) is a structural reparation mortar (class R3 according with EN 1504-3 [21]) which includes short glass fibres and silica fume. The second one (*A*) is an auto-levelling mortar which includes fibres and organic additives.

The flexural strength and compressive strength of each mortar batch was experimentally determined according with EN 1015-11:2000 [22]. The particular and average values for these properties, along with their coefficient of variation, in brackets, are summarised in Table 1.

2.2. Fabric

Two different fabrics were used to produce (P) FRCM specimens: carbon fibre (C) and basalt fibre (B). The properties of used meshes and constitutive fibres are summarised in Table 2. None of the fabrics was coated.

Tensile properties of a fabric are not equivalent to the tensile properties of a tow or the tensile properties of the corresponding fibre. Moreover, tensile strength depend on the testing setup, specimen geometry or fixation system. Thus, determining the representative ultimate tensile strength of fabrics when used in the particular prestressing configuration defined in this research (see the description of the setup in section 2.3 and Fig. 1) was essential. In addition, this specific characterisation of fabrics must be done before prestressing them in order to prevent overpassing its maximum capacity during samples production. Possible local stress concentration effects (because of mechanical connection of the fabrics to the prestressing system), the influence of the fabrics' shape (1600 mm free length and 50 mm width) and possible slight misalignment of fabrics in the prestressing system (see Fig. 1) might influence the tensile performance of fabrics reducing their apparent strength. Because of this, the prestressing system and the corresponding methodology (manual application of the load using tensors and controlled with