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Mechanical and bond properties of FRP anchor spikes in concrete and masonry blocks

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ABSTRACT

Fibre Reinforced Polymer (FRP) materials are extensively used to retrofit masonry and reinforced concrete structures. Failure occurs in most cases due to composite debonding from the substrate. The use of FRP anchor spikes was thus proposed to reduce premature debonding failure. In this work, the results of an extensive experimental program on the bond behaviour between the FRP anchor spikes and the substrate are first presented. They include both the mechanical characterization of carbon and glass FRP anchor spikes and pull-out tests from concrete and masonry blocks. In pull-out specimens, FRP anchor spikes are embedded into the block (embedded anchor spikes) or fanned-out on the substrate surface (fanned-out anchor spikes) with an epoxy resin. For different specimen configurations and materials, the bond behaviour of the FRP anchor is analysed. The mostly observed failure modes were the tensile failure of the anchor spikes, the debonding of the anchor spikes from the substrate or a combination of both. Nonlinear finite element simulations were finally performed to understand the bond behaviour between FRP anchors spikes and concrete substrate.

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1. Introduction

Fibre Reinforced Polymer (FRP) materials are nowadays widely used to strengthen and retrofit existing masonry and concrete structures [1]. FRP external reinforcement is considered to be a more efficient technique than other traditional methods due to a lot of advantages of the FRP materials, such as superior mechanical properties, the durability and the light weight that leads to rapid installation as well as low transportation and labour costs. Nonetheless, one of the major points of concern in the use of FRP strengthening systems is related to the bond strength between the FRP reinforcement and the substrate and to the bond durability under both environmental actions (harsh environments) [2] and mechanical loading (fatigue) [3]. In particular, premature debonding may occur due to the low substrate tensile strength or the weak bond strength at the interface between the FRP reinforcement and the substrate. Debonding may be delayed by using anchorage systems [4–8].

Many types of anchorage systems have been already studied in past researches [9], such as FRP anchor spikes, FRP transversal wrappings, FRP strips, U-Anchors, patch anchors, longitudinal chases, plate anchors, bolted angles, cylindrical hollow sections and ductile anchorage systems. They present different geometries, installation limits and force transfer characteristics [10,11]. Above all the types of anchorage system already described, the FRP anchor spikes will be studied in depth in this paper. Only few researches on this topic are available, furthermore, there are no specific rules or guidelines for the anchor spike design.

1.1. Problem statement and previous studies

The adhesion between the reinforcement and the substrate is a critical issue in FRP reinforcing systems. In order to prevent the debonding failure, the application of FRP anchor spikes, which are commonly assumed to resist axial and shear forces, is considered. FRP anchor spikes are strands of bundle fibres (see Fig. 1a) which are embedded or fixed into the concrete or masonry substrate by using epoxy resin.

The free end of the anchor spikes is fanned-out and fixed by epoxy resin in order to join the anchor spike to the FRP reinforcement (see Fig. 1b). In some cases, the anchor spikes are extended on the external surface opposite to the FRP reinforcement, fanned-out and fixed again by using epoxy resin (see Fig. 1b). In the first case, the embedded portion of the anchor spike (embedded anchor spikes) contributes to the axial resistance while in the second one the anchor end is fanned-out on the external surface (fanned-out anchor spikes) and provides a significant

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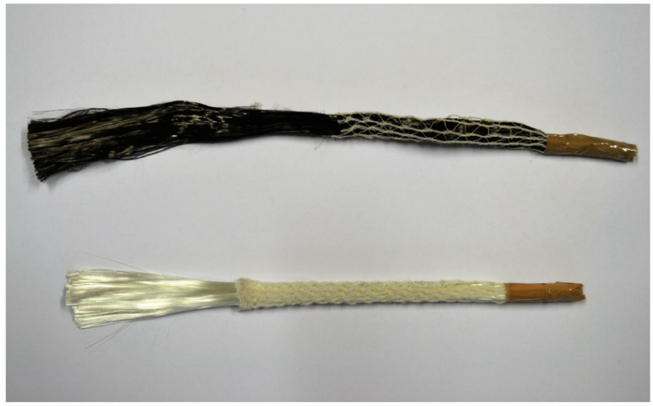
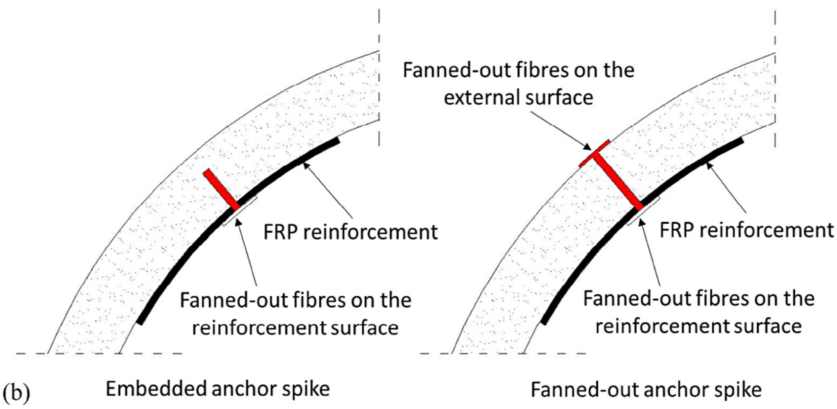


(a)



(b)

Fig. 1. Anchor spikes: (a) carbon (top) and glass (down) and (b) different uses of anchor spikes in practical situations.

contribution. They are usually installed orthogonal to or in plane with the FRP system, although other orientations may exist [9].

The role of the FRP anchor spikes in improving the FRP system strength is an interesting item studied by different research groups.

Orton et al. [12] reported the outcomes of an experimental program on concrete beams strengthened with CFRP strips anchored both with U-Anchors and with anchor spikes. The beams were notched at the centreline and subjected to bending tests. It was observed that the use of anchor spikes was more effective than U-Anchors. Moreover, anchor spikes having fan angle less than 90° showed a better mechanical performance.

Niemitz et al. [13] examined the efficiency of CFRP anchors by means of single shear tests on reinforced concrete blocks strengthened with CFRP sheets. They found that the use of FRP anchors was a viable technique in combination with FRP bonded sheets and then studied the effectiveness of FRP anchors with respect to geometric characteristics of the anchor.

A wide research on carbon and glass FRP anchors on concrete members has been performed at the Hong Kong University. As an example Zhang et al. [14] used FRP anchors to enhance the strength capacity of the FRP plates bonded to RC members. They highlighted the importance of the anchor fan configuration and of the dowel angle and defined a simply linear relationship between the angle of the anchor dowel and the joint strength enhancement. Smith et al. [15] studied the ability of FRP anchors to influence the load and deflection capacity of FRP-strengthened RC slabs. They analysed the influence of anchor location, geometry, inclination of anchor dowel angle and fibre content. Optimal anchor arrangements enabled the load and deflection capacities of the FRP-strengthened slabs, in relation to the unanchored but strengthened ones.

Kalfat and Al-Mahaidi performed a wide experimental campaign for the development of an anchor system able to improve the bond performance at the interface between the FRP reinforcement and the concrete substrate and to moderate premature failure of the joint [16,17]. In detail, anchor spikes were found to provide some anchorage improvement due to the dowel action.

Concerning the use of anchor spikes on masonry members, fewer studies were recently presented. Borri et al. [18] applied anchor spikes on masonry arches reinforced with GFRP sheets or CFRP plates. By performing an experimental campaign, it was observed that the use of anchor spikes could avoid the premature debonding of the reinforced system as well as the premature peeling. No evident increment in the load carrying capacity was highlighted due to the damage in the masonry caused by the drilled holes used for the insertion of the anchor spikes.

Caggegi et al. [19] performed experimental tests to quantify the efficiency of the CFRP anchors on the strength of a reinforced brick. When CFRP anchors were properly placed, an increase of the reinforcement resistance and of the dissipation capability was observed. Then, Fagone et al. studied the effects of mechanical anchors applied to FRP-to-masonry joints [20] and to masonry pillars [21]. In both cases they implemented near-end supported-single shear tests and analysed how the use of anchor spikes improved the performance of the reinforcement system. The experimental campaigns showed that properly designed mechanical anchors increased both the failure load and the ductility of the reinforcement. Finally, Caggegi et al. [22] performed an experimental study on bricks reinforced by using FRP sheets and fibre anchors with different configurations. The displacement field was used to describe the debonding process along the reinforced substrate and it was measured by means of a Digital Image Correlation optical non-destructive method. The analysis of the displacement field

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