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Bond performance of NSM – CFRP laminates using different surface treatments and cementitious adhesives

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Abstract

Carbon fiber reinforced polymer (CFRP) composites applied according to the near surface mounted (NSM) technique are nowadays regarded as an effective structural strengthening solution. However, despite the notable properties of polymeric adhesives, they present certain drawbacks such as the emission of toxic fumes and degradation of the mechanical properties after high temperature exposure. Thus, it is of great importance the research on alternative adhesives that guarantee similar target strengthening levels. Recent studies have been showing promising results with the use of cement based materials as adhesives due to their good ability for transferring stresses and compatibility to the substrate. However, further development of materials with improved performance are still required. The bonding properties in the case of carbon laminates applied according to the NSM strengthening technique still lag behind the desired requirements. This research explores the adoption of a pre-treatment procedure for carbon fibre laminates, aimed at increasing the bond strength between the cement based adhesive and the carbon fibre laminate applied according to the NSM strengthening technique. Pull-out tests results confirmed the effectiveness of the pre-treatment technique for enhancing the bond strength.

Keywords: FRP; Carbon laminate; NSM; Cementitious adhesive; Surface treatment.

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Introduction

Global concerns of civil engineering community have been directed to the infrastructures deterioration as one of the main problems. For instance, numerous amount of buildings and heritage structures suffer from degradation of performance. Hence, focusing on the repair and rehabilitation methods have been increasingly noticed in the current decade, which started by featuring the utilization of fiber reinforced polymer (FRP) based approaches. Different approaches of utilizing FRP composites have been introduced in the construction industry after being approved by several researches, such as externally bonded reinforcement (EBR) and near surface mounted (NSM) techniques. The latter case is receiving special attention due to the strengthening efficiency demonstrated in several experimental programs [1]. While the benefits of this technique has proven in different applications, it emphasizes the significance of improvements in NSM techniques, especially in areas where they show drawbacks such as exposure to elevated temperatures due to the low glass transition temperature (Tg) of the polymeric epoxy resins, which are generally used as the adhesive. These polymeric adhesives serve as the matrix to transfer the stresses between FRP and substrate, therefore finding an alternative incombustible material with low thermal diffusion to do so, is of a great importance. This problem has been addressed by different authors in recent years, exploring the potentialities of cement-based materials as substitute adhesives for the conventional ones [2-3]. Hence, implementing these materials to serve as the matrix in CFRP NSM systems can be a promising solution to overcome the problem of their utilization in cases of fire hazard.

In addition to the enhanced fire resistance, the high performance cement adhesive as a substitute of polymeric adhesives should ensure adequate bonding of FRPs to concrete substrate. Also, considering the relatively small dimensions of grooves in NSM technique, their suitable rheological characteristics are important to assure filling the grooves properly, as well as fast curing and the minimum possible shrinkage to avoid premature cracking. In this context, current paper presents a study on NSM technique with two different types of cementitious adhesives, using a simple and practical approach to improve the bond properties of surface treated CFRP laminates.

Experimental Program

To study the bonding performance of CFRP NSM systems with cement-based adhesives, direct pull-out tests were performed. Normal strength concrete with the strength class of C20/25 according to the Eurocode 2 was designed to cast concrete prisms with dimensions of 100×200×200 mm. In order to perform NSM strengthening, S&P Carbon laminates supplied by Clever Reinforcement with cross section of 1.4x10 mm^2 and average tensile strength and modulus of elasticity of 1909 MPa and 171 GPa, respectively, were used in this work.

<u>Cement-based adhesive</u>

In this research, two different types of cement-based adhesives were used to bond CFRP laminates to concrete substrate. First, a commercial material, modified in order to serve as the matrix in CFRP NSM system, herein designated as SMT. It is a 1-component, fibre reinforced mortar composed of sulphate resistant cement, selected aggregates (of maximum dimension 2.0 mm) and additives. However, to reach the desired product, the original product has been modified to improve flowability and shrinkage behaviour. The material was used in a previous research by authors [4] under the name of CBA_UM1 and performed as a promising solution for the high temperature vulnerability of polymeric matrices. However, further modifications took place to reach a better adhesive, which herein designated as CBA_UM2. Average compressive strength and elastic modulus of CBA_UM2 were 73.0 MPa and 35.9 GPa, respectively.

In addition to the commercial solution, an alternative adhesive, here named as AA_UM1, was also developed in this study and tested as the cement-based adhesive for the NSM system in direct pull-out test. The material consists of Portland cement 42.5 R, microsilica, fine sand, super plasticizer, shrinkage reducing admixture. Average compressive strength and elastic modulus of AA_UM1 were 106.9 MPa and 31.7 GPa, respectively.

<u>Surface treatment of CFRP laminates</u>

The CFRP laminates for NSM strengthening are generally used as smooth surfaced reinforcements, which lead to a minimum grip between the laminate and adhesive. Researches proved the effectiveness of physical bond improvement on maximum pull-out load capacity [4]. Hence, to improve bonding surfaces between CFRP laminates and forming an interlocking mechanism in the transition zone between laminates and cement-based adhesive, a sand treatment approach was adopted. Therefore, the laminates bonding surfaces were covered with a layer of sand, attached using S&M® 55 epoxy resin. Two types of sand treatment were used to cover the surfaces of laminates, Sika Carga2 TM with the maximum particle size of 0.2 mm, and a normal fine sand with the particle size in the range of 0.6 to 0.85 mm. The pre-treated laminates were then installed into the grooves after 7 days of curing the S&M® 55 epoxy resin, using the two aforementioned types of cement-based adhesives, AA_UM1 and CBA_UM2.

Pull-out test

Grooves with width of 10 mm and depth of 20 mm were executed in concrete prisms to benefit from a protective cover in case of high temperature exposure of the element surface, by deep installation of laminates. The bond length of laminates was designed to be 125 mm for all the tests. Insertion process started by wetting inside the grooves to avoid moisture absorption of substrate, followed by laying a layer of cement-adhesive inside groove and placing laminate. Then, the groove was filled with adhesive gradually to avoid leaving voids. The strengthened samples were covered with wet fabrics to preserve their moisture until the test after 28 days. Three identical samples of each strengthening scheme were prepared and tested. Samples were tested using a 50 KN load cell with the loading rate of 2 μm/s.

Results and discussions

Figure 3 presents the pull-out force and Table 1 summaries the obtained results for all tested series where NT, C2, and FS designate, non-treated, Carga2 treated, and fine sand treated laminates respectively; while CBA and AA stand for the respective cement adhesives. It indicates the higher ability of Carga2 treatment approach to increase the maximum pull-out force. Also the CBA_UM2 commercial adhesive demonstrated a better performance than the AA_UM1 adhesive. In case of untreated laminates, AA adhesive showed a slightly better behaviour, which could be due to the smaller grain size sand. However, the results clearly confirm the substantial effectiveness of the proposed surface pre-treatment procedure. All the specimens have failed by slippage of the CFRP laminate.

Conclusions

This study assessed experimentally the performance of CFRP NSM strengthening system, using two different types of cement-based adhesive for bonding surface treated carbon laminates to concrete substrate. Test results demonstrated that the adopted treatment approaches were able to improve the bonding performance up to 8 times in case of AA_UM1 and up to 15 times in case of CBA_2 with respect to the plain untreated laminates. It is also verified that Carga2 treatment has higher contribution than fine sand to improve the bonding performance. Moreover, the adopted technique could increase the average bond strength to about 8 MPa that sounds promising, comparing to the values close to 10 MPa which were registered in case of using conventional epoxy resin adhesives [5]. Assessing the performance of NSM technique using cement-based adhesives when submitted to high temperature is an ongoing task in this research project.

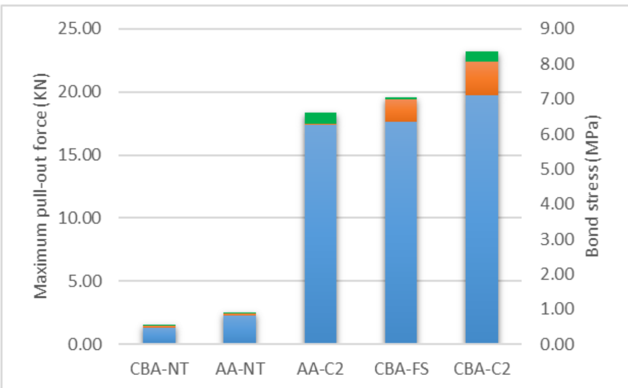

Figure 1. Pull-out force for different test series with three identical samples for each

Table 1. Pull-out test results

Label	Type of laminate treatment	Pull-out force [KN]	Loaded-end slip at maximum pull-out force [mm]	Free-end slip at maximum pull-out force [mm]	Average pull-out force [KN]	Average bond strength [MPa]
CBA-NT	-	1.31	0.05	0.01	1.44	0.50
		1.44	0.06	0.01		
		1.56	0.06	0.01		
AA-NT	-	2.26	0.20	0.11	2.38	0.84
		2.37	0.18	0.06		
		2.52	0.12	0.01		
AA-C2	Carga2	17.37	0.82	0.11	17.76	6.23
		17.50	0.61	0.14		
		18.40	0.85	0.18		
CBA-FS	Fine sand	17.58	0.82	0.08	18.84	6.61
		19.36	0.80	0.08		
		19.58	0.85	0.06		
CBA-C2	Carga2	19.72	0.86	0.09	21.79	7.65
		22.42	0.80	0.09		
		23.23	1.09	0.09		

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