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TEMPERATURE EFFECT ON THE BOND BEHAVIOUR OF A TRANSVERSELY COMPRESSED MECHANICAL ANCHORAGE SYSTEM

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ABSTRACT

Nowadays the strengthening of reinforced concrete (RC) structures using FRP composites is a viable reality, consolidated by many studies and practical applications. One of the most common methods used to apply the FRP is the externally bonded reinforcement (EBR) technique. However, the development of stresses at the anchorage zones of the EBR-FRP composite might cause premature debonding. To delay or avoid premature failure, mechanical systems were successfully developed. This works aims to assess the performance of a mechanical system: the metallic anchorage plate commercially distributed by S&P Clever Reinforcement Company, typically used for pre-stressed EBR-FRP systems. For that purpose, an experimental program composed by fourteen concrete blocks (200×500×800 mm^3) strengthened with EBR-CFRP laminates mechanically anchored to the concrete was executed. Each metallic plate was fixed to the concrete element through six prestressed bolts, creating a confinement stresses in the anchorage region. All specimens were tested up to failure under two types of pull-out configurations: the steady-state temperature, where the laminate was pulled from the block with increasing force and constant temperature (20 ºC, 60 ºC and 80 ºC); and the transient temperature, where the laminate was pulled with constant force (0.5% and 0.6% of strain) and the temperature was gradually increased. Besides temperature and test configuration, the influence of the laminate width and level of transverse compression in the metallic plate were also studied. Results showed that the debonding process and failure are highly influenced by the temperature, laminate width and confinement level.

KEYWORDS

Bond-behaviour, CFRP, EBR, Concrete, Transverse compression, Hight temperature.

INTRODUCTION

The use of fibre reinforced polymers (FRP) in the strengthening of reinforced concrete (RC) has been carried out in several practical cases with confidence and increasing knowledge. From the variety of FRP materials, the carbon FRP (CFRP) is frequently selected due to its higher strength, greater stiffness and fatigue life, less susceptibility against aggressive environments and creep rupture. The most common method for applying the CFRP material is through the externally bonded reinforced (EBR) technique. Typically cold-curing epoxy adhesives are used as bond agent (ACI 440.2R-08, 2008; CNR, 2013; Correia et al., 2015). In some strengthening applications, such as prestressing, anchorage systems are required to transfer the high shear stresses, commonly developed between the extremities of the FRP reinforcement and the concrete substrate, so as to avoid a premature FRP peeling-off failure (Correia et al., 2015; Kotynia et al., 2011; Sena-Cruz et al., 2016). The load capacity of an EBR system without end-anchorages is also limited by its effective bond length. In that sense, mechanical anchorage systems have been proven to improve the load carrying capacity of the strengthened element even further when transverse confinement is applied, mainly because the confinement level enables friction in the cracked interface (Biscaia et al., 2015; *fib*, 2013; Hansen et al., 2012). Nonetheless, there are concerns regarding the behaviour of EBR CFRP systems at elevated temperature. The strength and stiffness of these systems are severely diminished at moderately elevated temperatures, when the system is close to the glass transition temperature (T_g) of the bonding agent (60ºC-120ºC) (ACI 440.2R-08, 2008; Firmo et al., 2015). Considering that these temperatures are easily achieved in outdoor applications, the study on the behaviour of EBR systems under the effect of high temperatures is of utmost importance (Firmo et al., 2015; Firmo et al., 2012).

This paper aims at investigating the adequacy of a commercially available mechanical anchorage system. The influence of the laminate width, confinement provided by the torque level and the temperature are the main variables in an experimental campaign that included steady state and transient pull-out tests.

EXPERIMENTAL INVESTIGATION

Experimental program, specimens, and test configuration

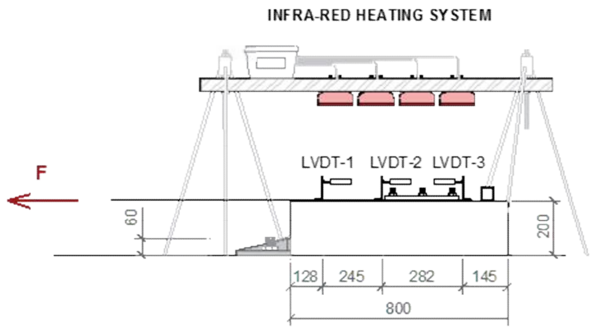
The experimental program is composed of 14 prismatic concrete specimens (200×500×800 mm^3) externally bonded with CFRP laminates of different widths (50, 80 and 100 mm) and a constant width of 1.2 mm (see Table 1). The CFRP laminates were mechanically anchored to the concrete surface through a hard-aluminium plate using six M16 8.8 bolt anchors. In order to study the effect of the transverse confinement, the torque level applied on each M16 bolt was controlled: (i) a torque of 100 N·m, and (ii) a value of 150 N·m, based on previous works (Correia et al., 2017; Correia et al. , 2015).

The preparation of the specimens was concluded after four steps: (i) first, the surface of the fourteen concrete blocks was enhanced using the sandblasting technique and six holes of 18 mm of diameter were drilled to accommodate the anchor bolts; (ii) after cleaning the concrete surface and its holes with pressurized air, the M16 metallic anchor bolts were fixed with a chemical bond agent (Type: Hilti HIT-HY 200-A®); (iii) then, the epoxy adhesive (Type: S&P Resin 220) was prepared according to the requirements provided by the supplier and applied on the previously cleaned CFRP laminate strip, on the concrete surface and on the surface of the metallic anchorage plate; (iv) finally the anchorage plate was placed in its predefined location and, the M16 anchor bolts were torqued using a dynamometric key that ensured the target level of confinement. The specimens were ready to be tested after 7-14 days of curing of the epoxy adhesive.

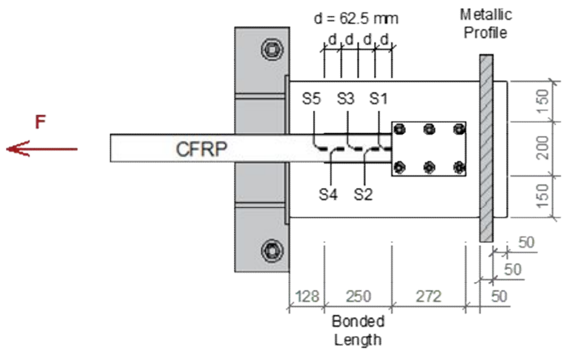
The CFRP laminate was bonded to the concrete block a total length of 522 mm, where 250 mm corresponded to the defined length of unconfined bonded region, followed by the anchorage plate (length of 272 mm). According to the CNR (2013) the unconfined bonded length (henceforth referred simple as "bonded length") surpasses the theoretical effective length needed to achieve the maximum debonding load.

The instrumentation included (i) three linear variable differential transformers (LVDT), (ii) five strain gauges, (iii) one load cell and (iv) five temperature sensors (thermocouples type k). The location of the LVDTs and strain gauges is presented in Figure 1-a and Figure 1-b, respectively. Each LVDT measured the relative displacement of the CFRP laminate to the concrete surface: one in the beginning of the bonded length (loaded end, LVDT-1), a second immediately after the anchorage plate (mid end, LVDT-2), and a third on the other side of the anchorage plate (free end, LVDT-3). The strain gauges were equally spaced (62.5 mm) along the CFRP bonded length. The temperature sensors were placed in two locations: (i) at the middle of the anchorage plate and (ii) at the middle of the bonded length.

The capacity and adequacy of the mechanical anchorage was accessed through a pull-out test set-up using two different configurations: the steady-state configuration, where the laminate is pulled from the block with increasing force and constant temperature (20 ºC, 60 ºC and 80 ºC); and the transient configuration, where the laminate is pulled with constant force (0.5% and 0.6% of CFRP strain) and the temperature is gradually increased until failure.



(a) Side view and instrumentation



(b) Top view and instrumentation

Figure 1: Top view and side view of the test set-up and instrumentation. Note: all units in [mm].

Steady state test configuration

The steady state test configuration was used in ten of the fourteen specimens. The test consists on a typical single shear test where one laminate end was pulled using a servo-controlled machine at a constant rate of 0.30 mm/min until the total debonding of the bonded length of the laminate is reached. Then the speed was increased up to 2 mm/min until the end of the test. During the steady state test a constant temperature of 20 ºC, 60 ºC or 80 ºC was kept at anchorage zone. The temperature was achieved using four infra-red (IR) heaters and a control thermostat. Details regarding the variables of the experimental program are presented in Table 1.

Transient test configuration

Similarly to the steady state tests, the transient tests used four IR heaters to gradually increase the temperature in the anchorage zone. In a first stage of the transient tests, the temperature was kept constant at 30 ºC in all specimen and the stress level on the laminate was increased up to a predefined value (0.5% and 0.6% of CFRP strain). Then the temperature was raised up until failure was obtained, always keeping the stress level constant. If the temperature reached 80 ºC and the failure was not observed, the conditions of temperature (80 ºC) and stress (0.5% and 0.6% of CFRP strain) were kept for a period of one additional hour before ending the test. The strain, temperature, and relative displacement of the laminate in relation to the concrete were continuously measured.

Materials

Two batches (B1 and B2) were used to cast the concrete blocks (see Table 1). Six cylindrical concrete specimens with 150 mm of diameter and 300 mm of height of each concrete batch were used to evaluate concrete properties. The modulus of elasticity and compressive strength were assessed using compression tests following the LNEC E397-1993:1993 and NP EN 12390-3:2011 recommendations, respectively. These tests were performed at the same age of the pull-out tests. From the results obtained, an average compressive strength of about 33.4 MPa (CoV=4.33%) and 45.0 MPa (CoV=1.24%) was obtained for batches B1 and B2, respectively. The modulus of elasticity was also assessed for batch B1 (30.8 GPa, CoV=2.84%) and for batch B2 (32.8 GPa, CoV=0.72%).

Table 1: Experimental program

Specimens	Laminate Width	Laminate Modulus of Elasticity	Laminate Tensile strength	Torque Level	Test Config.	Temp.	CFRP Strain	Concrete Batch
L50_T100_RT	50 mm	176.4 GPa (CoV=2.0%)	2222.4 MPa (CoV=4.7%)	100 N·m	Steady state	20 ºC	-	B1
L50_T150_RT	50 mm			150 N·m		20 ºC	-	B1
L80_T100_RT	80 mm	170.5 GPa (CoV=0.3%)	2428.0 MPa (CoV=4.6%)	100 N·m		20 ºC	-	B1
L80_T150_RT	80 mm			150 N·m		20 ºC	-	B1
L100_T100_RT	100 mm[(a)]	169.4 GPa (CoV=1.4%)	2480.2 MPa (CoV=4.0%)	100 N·m		20 ºC	-	B1
L100_T150_RT	100 mm[(a)]			150 N·m		20 ºC	-	B1
L100_T100_ET1	100 mm[(b)]	187.2 GPa (CoV=0.9%)	2895.2 MPa (CoV=4.4%)	100 N·m		60 ºC	-	B2
L100_T150_ET1	100 mm[(b)]			150 N·m		60 ºC	-	B2
L100_T100_ET2	100 mm[(b)]			100 N·m		80 ºC	-	B2
L100_T150_ET2	100 mm[(b)]			150 N·m		80 ºC	-	B2
L100_T100_T5	100 mm[(b)]			100 N·m	Transient	-	0.5%	B2
L100_T150_T5	100 mm[(b)]			150 N·m		-	0.5%	B2
L100_T100_T6	100 mm[(b)]			100 N·m		-	0.6%	B2
L100_T150_T6	100 mm[(b)]			150 N·m		-	0.6%	B2

Note: The laminate 100 mm of width used in the present study belongs to two different laminate batches, batch [(a)] and batch [(b)].

The CRFP tensile properties were assessed throughout ISO 527-5:2009 recommendations. Four different laminates were used: one with the cross-section of (i) 50×1.2 mm^2; a second with a cross-section of (ii) 80×1.2 mm^2; a third with a cross-section of (iii) 100×1.2 mm^2 from the batch [(a)], used only in steady state tests at room temperature; and a forth with the cross-section of (iv) 100×1.2 mm^2 from the batch [(b)] used all specimens subjected to high temperatures (results are summarised in Table 1).

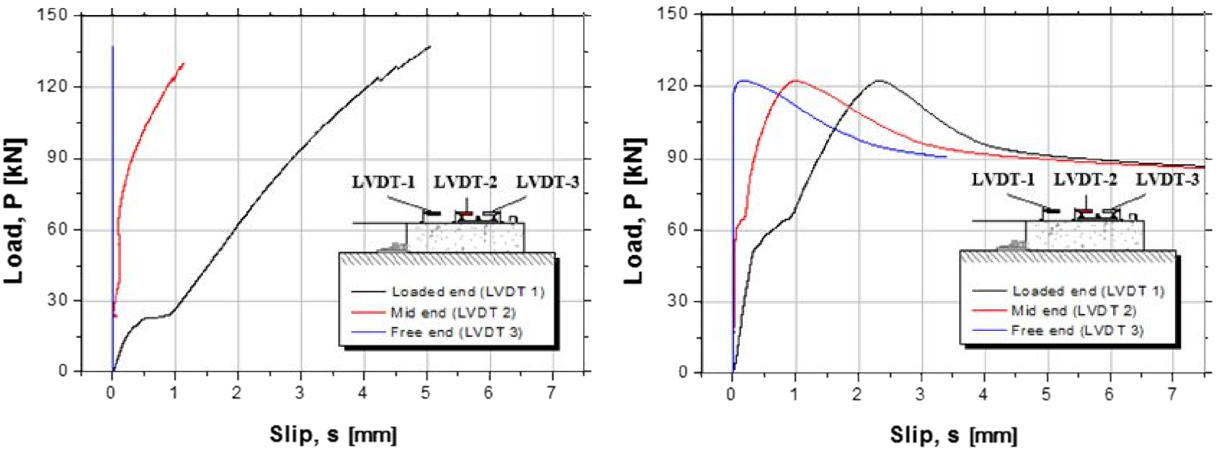
A two-component epoxy resin (type S&P Resin 220) was used to bond the CFRP laminate to the concrete substrate. Based on an assessment of its properties previously made in another experimental program, a modulus of elasticity of 7.2 GPa (CoV=3.7%) and a tensile strength of 22.0 MPa (CoV=4.5%) are expected (Silva et al., 2016).

RESULTS AND DISCUSSIONS

Steady state tests

The main variables studied in the steady state tests are the laminate geometry, the confinement level induced by the torque level in the mechanical anchorage and the temperature. Different behaviours were observed for specimens tested at room temperature (20 ºC) and at elevated temperatures (60 ºC and 80 ºC). Figure 2 shows the typical pull-out load-slip response observed on tests carried out at room temperature and elevated temperatures.

As can be seen in Figure 2-a at room temperature, the test starts with an almost linear branch at the loaded end. Then the debonding of the laminate from the concrete substrate starts to occur and, in the loaded end, the registered slip increases while the load level remains almost constant. The complete debonding of the FRP is observed when the mid end LVDT starts to register displacements. After this stage, the pull-out load is gradually increased simultaneously with the relative displacement observed at the loaded end and the mid end until rupture of the CFRP is attained. In all tests carried out at room temperature, failure was obtained when the CFRP laminate reached its maximum tensile capacity. Also, at room temperature, no slip could be observed at the free end. From these results it was clear that the mechanical anchorage used in this experimental programme provides adequate transverse confinement of the laminate to the concrete substrate regardless of the applied confinement level. Figure 2-b shows the load-slip behaviour of specimen L100_T150_ET2, which is representative of all specimens tested at elevated temperatures. Similarly, to the tests carried out at room temperature, the LVDT placed on the loaded end is the first to register displacements. The displacement registered at the loaded end increases almost linearly with the pull-out force until the debonding initiation. The complete debonding of the laminate can be identified when the LVDT placed on the mid end stats to register movement. However, the onset of the debonding process is found to occur at the very early stages of the test, due to the effect of temperature on the epoxy adhesive. Further details on the debonding process are given in the following paragraphs. From complete debonding onwards, the slip increases in both locations (loaded end and mid end). Then, the maximum force is reached and displacements in the free end are observed, marking the anchorage failure. Once the maximum force is reached, displacements in all the three LVDTs increase while the pull-out load decreases. However, the load does not decrease to zero, but stabilizes at a load level that represents a residual and constant bond stress. This last behaviour was also observed in other works, e.g. (Biscaia et al., 2015).

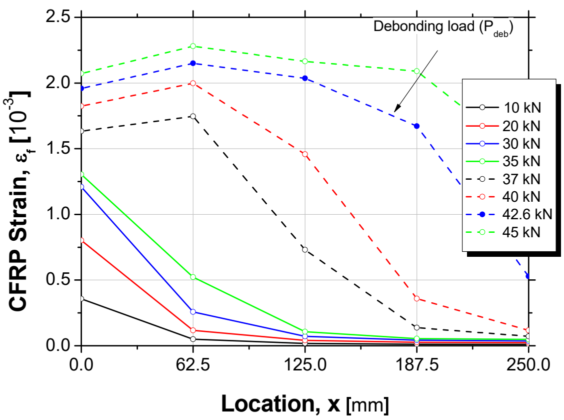


(a) Room temperature – L50_T100_RT *(b) Elevated temperature – L100_T150_ET2*

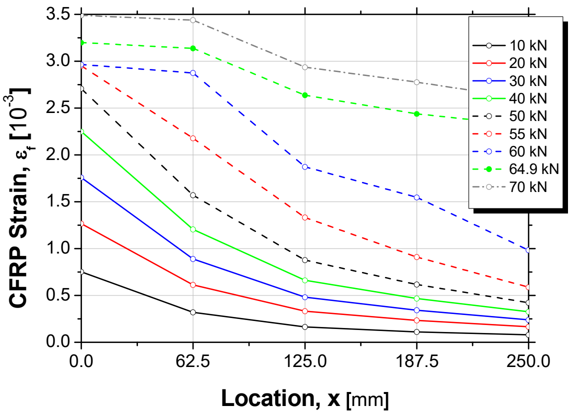
Figure 2: Typical load-slip behaviour for specimens tested at room temperature and at elevated temperature.

The results, in terms of debonding load (P_{deb}), ultimate load (P_u), ultimate strain (ε_u) and mode of failure are shown in Table 2. Figure 3 shows the typical strain evolution across the bonded length of specimens tested at room temperature and at elevated temperature. In the current experimental program, the debonding load corresponds to the maximum load that is supported by the bonded length, before the metallic anchorage starts to be solicited to support the pull-out force. It should be noted that the debonding process for specimens tested at room temperature was a quick and fragile event, which was easily identified with the initiation of slip in LVDT-2. During the first stages of the loading at room temperature, the strain has a peak value at the loaded end (location x=0mm, see Figure 3a) and null values near the anchorage plate (location x=250mm, see Figure 3a). As the load increases, the strain in other sections of the bonded length starts to increase and the strain profile changes. The increase in strain near the anchorage plate occurs simultaneously with the start of register movement with LVDT-2. Is the swift and simultaneous increase of values registered in both sensors that mark

the complete debonding of the specimens at room temperature. Immediately after this point, the strain and displacement continue to increase but at a lower rate. At room temperature, the bonded length (250 mm) is long enough to develop the maximum debonding load and, according to the CNR (2013), the expected debonding loads for the laminates with the geometry of 50×1.2 mm^2, 80×1.2 mm^2 and 100×1.2 mm^2, are equal to 27.0 kN, 42.5 kN and 53.0 kN, respectively. This shows that the experimental results are in accordance with the expected values.
When the tests were performed at high temperatures, differences in the debonding process were observed. As shown in Figure 3, the strain evolution on tests carried out at elevated temperatures showed an almost linear strain evolution, with a peak value on the loaded end (location x=0mm, see Figure 3b) and a gradual decrease towards the anchorage plate (location x=0mm, see Figure 3b). Contrary to tests carried out at room temperature, all strain gauges showed an increasing strain variation since early load stages. Also, due to the different strain evolution, it could be observed that for the same load level, the high temperature tests showed lower strain values. One possible explanation resides in the fact that the temperature have changed the epoxy adhesive's properties, once the temperature at the adhesive during the debonding is close to the glass transition temperature (T_g). In two recent studies carried out by the authors (Emara et al., 2017; Silva et al., 2016) the S&P Resin 220 was characterized and, according to the ISO 6721 (2001), the Adhesive's T_g varied between 47 ºC and 52 ºC (epoxy cured at room temperature before testing). The transition from a solid to a viscous state is a continuous process over a temperature range of 10-20ºC (Michels *et al.*, 2015) and, for the temperature used in the steady state tests (see Table 1), it seems that the there was an increase on the ductility of the adhesive. The reduction in the adhesive stiffness might be responsible for smoothing the shear stress/strain distribution (Firmo et al., 2015). Because the strain near the anchorage plate increased since the beginning the test, the debonding load could not be easily identified. Also in specimens tested at elevated temperatures, the LVDT-2 started register small displacement variations since early test stages.



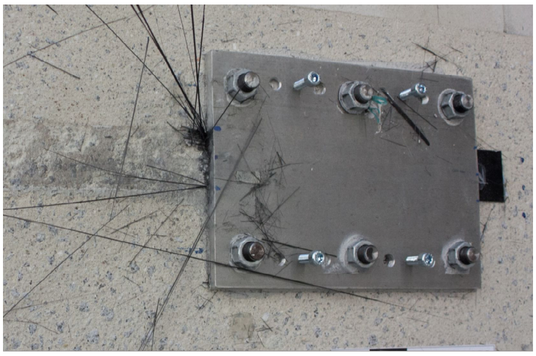
(a) Room temperature – L100_T150_RT



(b) Elevated temperature – L100_T150_ET2

Figure 3: Strain profile for specimens tested at room temperature and at elevated temperature.

As stated before, the tests carried out at room temperature failed by CFRP rupture at its maximum tensile capacity (see Figure 4a), except for the case of specimen L80_T150_RT, where its maximum capacity was not attained because the camping system failed to hold the pulled end of the CFRP. The elevated temperatures, however, changed the failure mode from CFRP rupture to anchorage slippage (see Figure 4b) and, consequently, the ultimate load (P_u) registered for specimens tested at 60 ºC and 80 ºC was reduced to 58.5% and 44.5% of the values observed for specimens at room temperature, respectively. Contrarily to CFRP rupture, the failure by anchorage slippage did not result in a swift decrease of load down to zero, but to a softened reduction of the supported load down to a residual value of 60.5-66.2% of its maximum capacity. The bond stress responsible for the residual supported load is a consequence of the transverse confinement stresses applied on the anchorage zone. As expected, this residual capacity is greater in specimens with the torque of 150 N·m (125.1 kN and 84.9 kN for specimens L100_T150_ET1 and L100_T150_ET2, respectively) than in specimens with the torque of 100 N·m (103.3 kN and 75.7 kN for specimens L100_T100_ET1 and L100_T100_ET2, respectively). The influence of torque level is also present in the ultimate parameters (ultimate load, P_u, and ultimate strain, ε_u) of specimens tested at elevated temperatures. The increase of torque from 100 N·m to 150 N·m lead to an average increase of 20.3% and 14.5% in the P_u of specimens tested at 60 ºC and 80 ºC, respectively. Nevertheless, the temperature is the major influential factor in all ultimate parameters. As can be seen in Table 2, the high temperatures reduced the P_u and the ε_u in 41.5-55.5% and 45.1-64.5%, respectively.



(a) FRP Rupture observed at room temperature – L50_T150_RT

(b) Anchorage Slippage observed at elevated temperature – L100_T150_ET2

Figure 4: Failure mode observed in specimens tested (a) at room temperature and (b) at elevated temperatures.

Transient tests

From the steady-state tests performed at room temperature it was possible to conclude that the mechanical anchorage plate provides adequate transverse confinement and the capacity to reach the maximum tensile capacity of the CFRP laminate. In the transient tests, two specific stress levels were imposed to the CFRP laminate and, for each stress level, it was possible to observe the maximum temperature supported. The ultimate temperature (T_u) registered in the anchorage is presented in Table 2 and the slip evolution in the loaded end, mid end and free end with the temperature is shown in Figure 5 for specimens tested at a constant stress level of 0.5% and 0.6%. Figure 5 also shows the time when the temperature started to increase (t_i), when the maximum predefined temperature was reached (t_f) and when failure was observed (t_u).

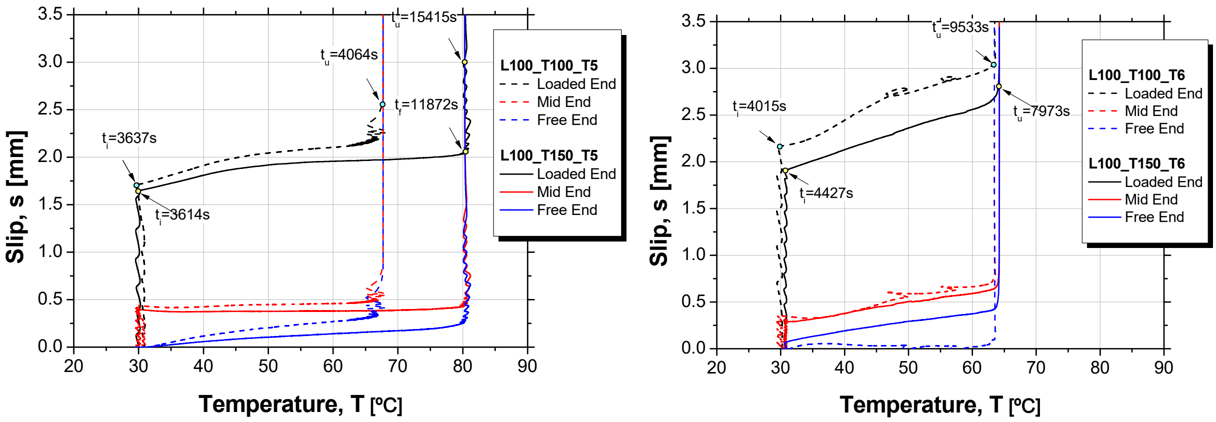
Table 2: Main Results

Specimens	P_{deb}[kN]	P_u[kN]	ε_u[10-3]	T_u[ºC]	Failure Mode
L50_T100_RT	23.5	137.5	13.4	-	FRP Rupture
L50_T150_RT	27.3	137.6	13.5	-	FRP Rupture
L80_T100_RT	42.7	258.8	15.1	-	FRP Rupture
L80_T150_RT	43.0	171.2$^{(1)}$	9.7$^{(1)}$	-	-$^{(1)}$
L100_T100_RT	55.5	294.0	15.1	-	FRP Rupture
L100_T150_RT	42.6	297.6$^{(2)}$	15.3$^{(2)}$	-	FRP Rupture
L100_T100_ET1	-	157.1	7.6	-	Slippage
L100_T150_ET1	-	189.0	9.1	-	Slippage
L100_T100_ET2	-	122.6	4.9	-	Slippage
L100_T150_ET2	-	140.4	5.9	-	Slippage
L100_T100_T5	-	-	-	67.7	Slippage
L100_T150_T5	-	-	-	80.0	Slippage
L100_T100_T6	-	-	-	63.4	Slippage
L100_T150_T6	-	-	-	64.2	Slippage

Note: P_{deb} – Debonding load; P_u – Ultimate load; ε_u – Ultimate strain; T_u – Temperature on the anchorage; $^{(1)}$ – Premature slippage from the clamping system; $^{(2)}$ – The ultimate load was not registered due to a technical problem - this value corresponds to the theoretically expected result;

Specimens tested under the transient configuration exhibit the same failure mode than those tested under the steady state configuration at elevated temperatures, which was slippage from the anchorage (see Figure 4b). For the case of specimens tested at the lowest stress level, 0.5% of CFRP strain (≈36% of the ultimate CFRP tensile capacity), failure was observed when the temperature at the anchorage was of 67.7 ºC (L100_T100_T5) and 80 ºC (L100_T150_T5), depending on the torque level. For this specific stress level, the confinement level induced by the level of torque proves to be a major factor in the anchorage capacity: the specimen with the lowest torque level failed when the temperature reached 67.7 ºC (above the adhesive T_g), whereas the specimen L100_T150_T5 not only supported the highest predefined temperature (80ºC, well above the adhesive T_g) but also endured almost one hour at those conditions before slippage failure.

As can be seen in Figure 5a, specimen L100_T150_T5 showed a displacement increase in all three locations after reaching the maximum predefined temperature (t_f=11872s). However, the registered slip, which was almost negligible in the first 30 minutes, gradually increased up to 1 mm in all LVDT's just before failure was observed (t_f=15415s). The remaining two specimens, tested with the highest stress level of 0.6% of CFRP strain (≈43% of the ultimate CFRP tensile capacity), failed shortly after the temperature in the anchorage surpassed the adhesive T_g. The specimen L100_T150_T6 failed at 64.2 ºC when the specimen L100_T100_T6 failed at 63.4 ºC, showing that there was a small increase of anchorage resistance with the confinement level. However, for this specific stress level, the confinement level has a considerable lower influence in the anchorage resistance when compared with the specimens with the stress level of 0.5% of the CFRP strain.
In short, the transient tests results showed two possible scenarios when the stress level is the studied variable: (i) in the first scenario (stress level 0.5%), failure is observed but it is highly influenced by the confinement level; and (ii) the second scenario is related to the highest stress level (0.6%), for which failure is attained shortly after the specimens temperature is at the adhesives T_g, regardless of the confinement level.



(a) Initial CFRP strain of 0.5% *(b) Initial CFRP strain of 0.6%*

Figure 5: Slip versus temperature in specimens with the initial CFRP strain of 0.5% and 0.6%.

There is a good relation between the results obtained using the transient tests configuration and the steady state test configuration. Both specimen L100_T150_T5 and L100_T150_ET2, failed at the temperature of 80 ºC and at similar stress levels. It is a fact that the ultimate strain in L100_T150_ET2 is higher than the strain level in L100_T150_T5, but, as referred before, in this transient test slippage was observed after one hour at 80 ºC. Likewise, specimen L100_T100_ET2 failed with the ultimate strain of 0.5% for a temperature of 80 ºC. These three specimens appear to indicate a critical synergy event when for the temperature of 80 ºC and the CFRP strain level of 0.5%. In steady state tests at 60 ºC, the CFRP ultimate strain was always superior to the predefined stress levels of the transient tests. Also, in both test configurations the confinement level appears to be a relevant factor in increasing the anchorage capacity.

CONCLUSIONS

An experimental program was carried out to assess the performance of a mechanical anchorage of EBR CFRP system to concrete structures. Two test configurations were used, steady state and transient, to test 14 prismatic blocks externally bonded with CFRP laminates. From the obtained results the following conclusions can be pointed out:

- In this experimental program, the mechanical anchorage showed adequate transverse confinement of the laminate to the concrete substrate at room temperature. Regardless of the level of confinement (100 N·m or 150 N·m), the anchorage allowed the use of the maximum capacity of the CFRP laminate;
- Distinct failure modes were obtained during the steady state tests: (i) FRP rupture was observed for specimens tested at room temperature, whereas (ii) anchorage slippage was observed in all specimens tested at elevated temperatures. A reduction on the ultimate load of 58.5% and 44.5% was observed for specimens tested at 60 ºC and 80 ºC, respectively, with respect to specimens tested at room temperature;
- At room temperature, the debonding load increased with the laminate width and a good correlation between the experimental values and the prediction from the literature;
- In the transient tests, two different outcomes were observed: (i) specimens with the lower stress level (0.5%) failed by anchorage slippage, but the confinement level played a critical role in the anchorage capacity; and (ii) the high stress level (0.6%) lead to the anchorage failure shortly after reaching the adhesives T_g.

- The torque level was the tool used to control the confinement level of the anchorage and, based on the results from both test configurations it appears to be a relevant factor in increasing the anchorage capacity.

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