ON THE EXPERIMENTAL STUDY OF THE INTERFACE BETWEEN A FIBER COMPOSITE LAMINA AND CONCRETE

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SUMMARY

In order to properly evaluate the failure characteristics and the strength of the bond between concrete and a fiber reinforced polymer (FRP) lamina, it is necessary to study the shear failure of the corresponding interface under different loading conditions. Two test configurations that permit such characterization are discussed here. The first is applicable to thin surface bonded laminas, and the test is performed using two standard concrete cylinders joined by the laminas and subjected to uniaxial tension. The second is applicable to laminates that are bonded on the surface or inserted into cuts made on the surface. The specimen is made up two blocks with a hinge between them and is loaded in bending. The results can help identify the mechanisms that could be of practical interest in structural applications.

1- INTRODUCTION

Fiber reinforced polymer composite laminas are commonly being used in the repair and strengthening of concrete structures. When these laminas are bonded to the surface of the element to prevent cracking or the widening of an existing crack, the composite action is governed by the behavior of the interface between the two materials. When the interface is subjected to shear forces, it could result in delamination due to the initiation and propagation of a crack within or along the interface. If the interface is sufficiently strong, structural failure occurs due to cracking or crushing of the concrete or the rupture of the lamina.

To study the failure behavior of the interface it is essential to develop and employ appropriate testing methods that permit controlled crack propagation in a well-defined interface. Two experimental techniques are discussed in the present work. In the first, a surface-bonded lamina is subjected to shear along the interface using uniaxial tensile loading, and in the second, a bending configuration is used to progressively pull out a laminate inserted into the concrete.

2- UNIAXIAL TENSILE TEST FOR SURFACE-BONDED LAMINAS

With the aim of applying a shear force along the interface between concrete and carbon fiber reinforced polymer (CFRP) laminas, three CFRP strips were bonded, at 120º to each other, across two 150×300 mm cylinders placed end-to-end, as in Figure 1(a). The cylinders are bonded onto the loading plattens of a servohydraulic testing machine and a uniaxial tensile load is applied. The debonding or slip is measured as the separ[illegible] ends of the two cylinders using 3 LVDT sensors placed around the circumference, a[illegible]igure 1(b). Three laminas were used in order to provide symmetry at least until th[illegible]f the first CFRP-concrete interface or the CFRP lamina itself. Also, each of the lam[illegible]nded over a longer length on the bottom cylinder to induce failure in only one of th[illegible]eas. Furthermore, a small area at the cylinder-cylinder interface was left unbonded[illegible] simulate a defect in the bonded area and to induce the interfacial crack. The differ[illegible]f the lamina are described in Figure 1(c), where L_c is the length of each concrete cyli[illegible]s the length (40 mm) over which the lamina is unbonded, and L_{b1} and L_{b2} are the[illegible]d longer bonded lengths, respectively (with L_{b2} = 1.5× L_{b1}).

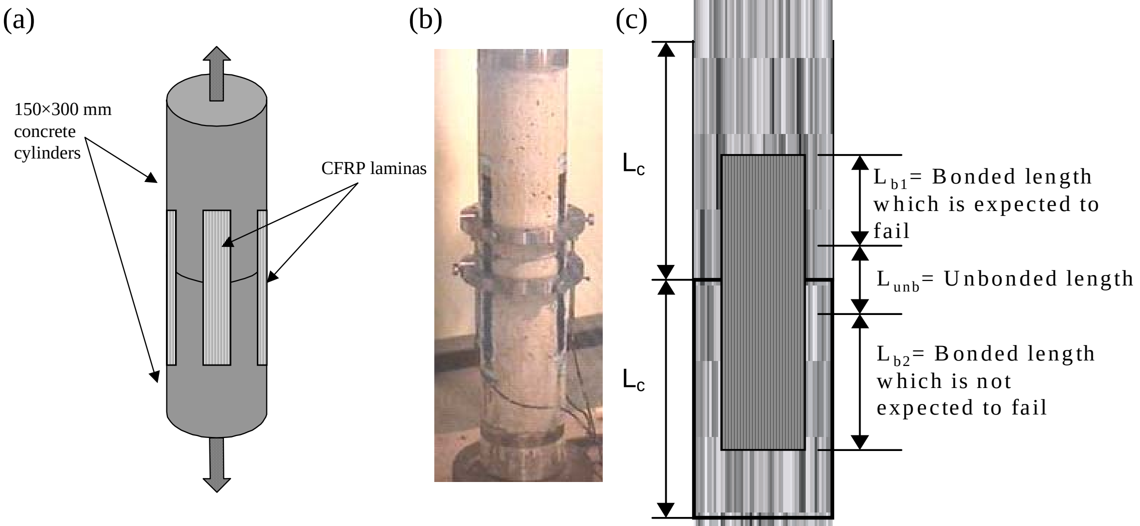

Figure 1. (a) Strips bonded across the ends of the cylinders, ([illegible] and (c) bonding scheme

The test results reported here correspond to concrete wit[illegible]e compressive strength of 48 MPa and CFRP laminas made up of a 0.117 mm thic[illegible]unidirectional fibers in an epoxy matrix. The modulus of elasticity of the lamina was[illegible]l, through tension tests, to be 182 GPa. The values of L_{b1} and the lamina width (w) were varied in order to study their influence on the failure load. The mean maximum load (P_{max}), from 3 trials, for each type of test and the corresponding failure load per unit lamina width (p_f) are given in Table 1. It was seen that the maximum load has a low variability and is a conservative estimate of 3 times the failure load of an individual interface. A typical load-slip diagram obtained in a test is shown in Figure 2, where each sudden drop in load corresponds to the complete debonding of a CFRP-concrete interface. Before the first drop there is an initial linear regime, beyond which there is a nonlinear response due to progressive debonding and/or the deformation of the interface. More details of the tests and their results can be seen in [1].

Considering the effect of the width of bonded laminate (i.e., L_{b1}=100 mm) first, it can be seen that P_{max} increases with an increase in w, as expected, but it is not proportional to w. This is clearer when the trend of p_f is observed, with the value of p_f decreasing with an increase in w, until about 60 mm. It appears that there is a size effect, as in other fracture phenomena, with higher unit loads for very small widths. This is important for the evaluation of the bond strength and clearly indicates that a minimum bonded width should be used to get representative results. In the present system, a minimum width of 60 mm should be considered.

Table 1. Failure loads

L_{b1} (mm)	w (mm)	P_{max} (kN)	p_f (N/mm)
100	20	8.7 (±0.3)	135
100	40	14.6 (±0.9)	122
100	60	19.2 (±1.3)	107
100	80	26.4 (±1.6)	110
25	40	10.2 (±0.1)	136

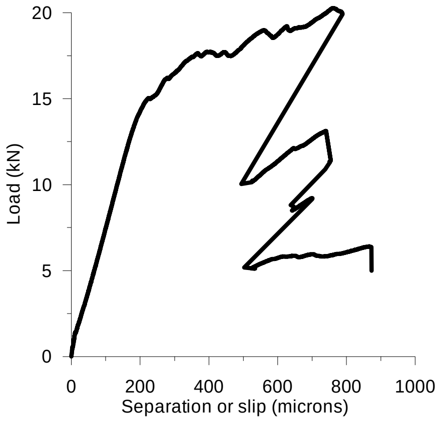

Figure 2. Typical load-slip curve

In terms of the bonded length, considering the tests with w=40 mm, it can be seen that the maximum load increases and reaches a constant value beyond L_{b1}=50 mm, approximately. This is also seen in the trend of p_f, which increases and then remains constant at about 120 N/mm. This trend can be used to determine the minimum bonded length and the bond strength of the interface in shear.

3- BOND FAILURE OF FRP INSERTS IN A BENDING TEST

Recent studies [2] have shown that the inserting and bonding of rigid laminates in cuts made into the surface of a concrete element can be more beneficial in certain applications than bonding the FRP lamina over the surface. In order to study the behavior of such systems, a pullout test has been used, where two blocks with a hinge between them is loaded as a beam after inserting and bonding the FRP laminate on the tensile face. The configuration is shown in Figure 3.

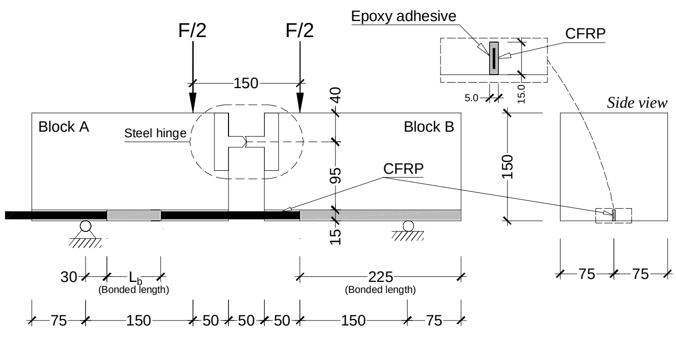

Figure 3. Bending test configuration for the evaluation of FRP inserts

In the present study, a 15 mm deep and 5 mm wide saw cut is made along the middle of two concrete blocks. The CFRP laminate, having a depth of 10 mm and a width of 1.4 mm, is inserted in the cut and bonded with an epoxy over the required length. The bonded length was 225 mm in block B and varied in Block A to have only the latter failing in the test. LVDT sensors were used to measure the slip on either end of Block A. The concrete used had a compressive strength of 41 MPa and an elastic modulus of 32 GPa. The laminate had an elastic modulus of 171 GPa.

Load is applied at both thirds of the span. The pullout force at the center of the CFRP laminate is calculated from the lever arm or using the strains measured with gages glued on the laminates (through the elastic modulus). Typical pullout force-slip diagrams are shown in Figure 4 for the slip recorded at the loaded and free ends of the laminate. It is clear that progressive debonding occurs with softening-type behavior followed by a residual frictional resistance during the pulling out of the laminate.

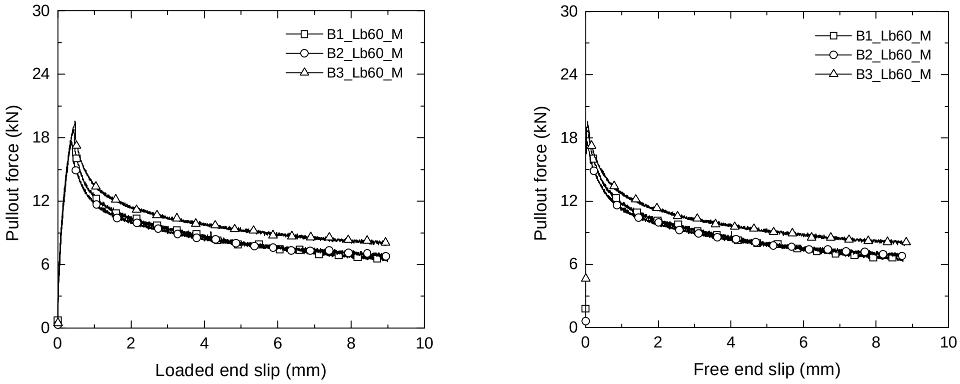

Figure 4. Typical pullout force-slip diagrams for the loaded and free ends

The influence of the bond length (L_b) and the load history have been analyzed. It was seen that span of the pre-peak nonlinear regime and the value of the peak pullout force increase with L_b, with a nominal bond strength of 10 to 14 MPa, which decreases with the increase of L_b. In the cyclic tests, the envelope of the pullout load-slip curves was similar to that obtained under monotonic loading. More details of the tests and results can be seen in [3].

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REFERENCES

[1] dos Santos, A. C., Gettu, R. and Bittencourt, T. (2001), Study of the bond failure between carbon fibers and concrete under shear. In: J. Figueiras et al., editors, *Composites in Construction*, A.A.Balkema Publishers, Lisse, The Netherlands, pp. 223-226.

[2] Barros, J. A. O. and Dias, S. J. E. (2003), Shear strengthening of reinforced concrete beams with laminate strips of CFRP. In: D. Bruno et al., editors, *Proc. Intnl. Conf. on Composites in Construction (Cosenza, Italy)*, pp. 289-294.

[3] Sena-Cruz, J. M., Barros J. A. O. and Gettu, R (2004), *Bond behavior of Near-Surface Mounted CFRP laminate strips under monotonic and cyclic loadings*, Report 04-DEC/E-04, Dept. of Civil Engng., School of Engineering, University of Minho, Guimaraes, Portugal.