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Advanced test method to study bond of NSM reinforcements

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ABSTRACT: Application of Fibre Reinforced Polymers (FRP) had increasing significance over the last decades for strengthening reinforced concrete (RC) structures. In NSM (Near Surface Mounted) strengthening technique the FRP material is bonded into grooves cut in the concrete cover. This technique has been living its renaissance since the end of the 90's. In comparison to other strengthening applications the NSM strengthening is rather complex. In order to study the bond behaviour great amount of experiments need to be performed owing to the high number of variables. Authors of present article realized that the influence of the experimental conditions on the bond behaviour was not yet studied enough in details, even though it can also have very important influence. To overcome this issue, authors developed an advanced pull-out test setup which has several advantages when comparing to other tests methods used to study bond behaviour of NSM reinforcements. Results by using the herein presented advanced test method (including L-shaped specimen), were compared to double tension-tension test results, in order to assess the differences in bond behaviour of FRP reinforcements.

1 INTRODUCTION

The use of NSM reinforcement is not an absolutely new technique. It was developed in Europe for strengthening of RC structures in the early 1950's. The FRP (Fibre Reinforced Polymer) materials opened new perspectives of NSM strengthening as the disadvantages of steel reinforcements (such as electrolytic corrosion and lower bond strength due to the reduced concrete cover) could be avoided by the FRP material.

FRP materials can assure proper confinement, bending and flexural resistance of reinforced concrete elements. The advantages of FRP materials when comparing to steel are: insensitivity to electrolytic corrosion, high tensile strength to weight ratio, high rate of application etc. However, some disadvantages need also to be considered such as: sensitivity to high temperatures, high material cost etc. (*fib*, 2001; Szabó et al, 2007).

The NSM strengthening technique has several advantages in comparison to EBR, such as: reduced preparation time (grinding or surface levelling is not needed), available bond surface will be increased (more than doubled for strip shaped reinforcement), possibility to apply a larger variety of reinforcement (consider the round shaped reinforcements developed for internal reinforcement), and many others (Szabó, 2008).

Effect of the testing conditions on the bond behaviour was not previously studied in detail. The authors aim with the present paper is to draw attention to this fact, but also to present an advanced pull-out test specimen for investigation of the bond behaviour of NSM reinforcement.

2 BOND OF NSM REINFORCEMENT

2.1 *Interaction between the strengthened structural member and the strengthening materials*

Bond behaviour influences not only the ultimate capacity of the element but also serviceability behaviour, crack widths and crack spacing. In case of strengthening with FRP the most important issue is the stress transfer between the strengthened structural member and the strengthening material (Tepfers et al, 2003). The interaction force development (Figure 1) between the strengthened structural member and the strengthening materials is different in case of NSM and EBR (Externally Bonded Reinforcement) applications. In addition to the shear stresses parallel to the FRP surface, stresses perpendicular to the FRP surface develop. These perpendicular stresses are different in nature and intensity. In NSM applications they are mainly balanced by the concrete surrounding the groove which confines the strengthening (adhesive and strengthening). As a result of the confinement deformations of the adhesives will be limited, and the so developed tri-axial stress state will enhance the adhesive shear and bond capacities. In EBR applications the interaction stresses perpendicular to the surface are balanced only by the adhesive or concrete surface tensile strength (Szabó, 2008).

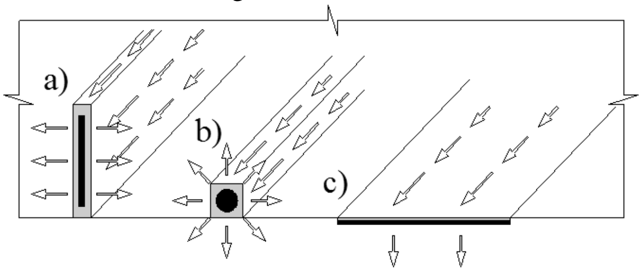

Figure 1. Interaction forces developed by: a), b) near surface and c) externally bonded reinforcements.

2.2 *Parameters affecting bond of NSM FRP reinforcements*

The most important factors influencing the bond properties of NSM reinforcements are considered to be the following.

Material factors: modulus of elasticity (deformation capacity) and strength of the substrate material, bonding system (high strength adhesives) and strengthening material.

Geometrical factors: the size, shape and the surface of the groove and reinforcement. The edge distance is considered to be also an important geometrical factor.

Presented factors have importance in the internal stress development, possible failure modes and load carrying capacity of the bonded connection (Szabó, 2013).

2.3 *Test methods*

For investigation of bond stresses simple pull-out tests (de Lorenzis et al., 2002; Seracino et al., 2007), beam pull-out tests (Cruz et al., 2002) or double tension-tension tests can be used.

2.3.1 Beam test

In case of beam tests, the specimens consist of one or two prismatic blocks (Figure 2). If one block is used (Kotynia et al., 2009; de Lorenzis et al, 2001) it usually has a hinge at the compression flange (in the middle of the span). If two blocks are used (Cruz et al, 2002) they are joined by a hinge in the compressed flange and by the tested reinforcement in the tension flange. The tested NSM reinforcement can be divided into three lengths categories as shown in Figure 2:

(1) the monitored bond length, symmetrically to this is (2) the anchorage bond length and in the middle of the span (3) the unbounded length is located.

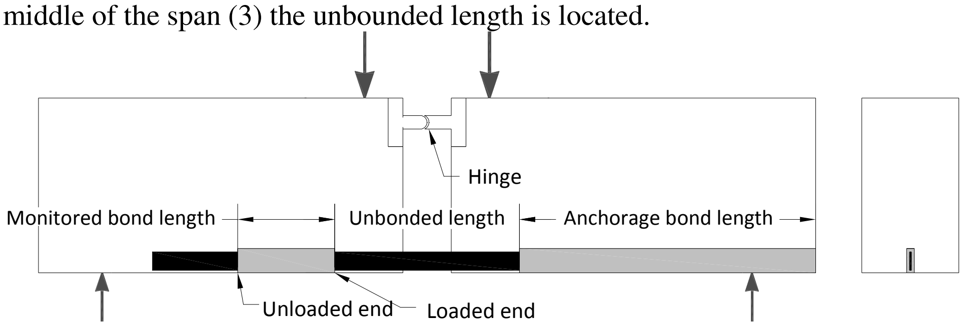

Figure 2. Schematic representation of beam test.

2.3.2 Pull-out test

Pull-out tests are the most common tests for bond analysis. The shape of the specimens is based on the classic RILEM test setup used for internal reinforcements. Advantages of pull-out tests are: manageable specimen size and reduced material use, and the ability to perform high number of tests. Common disadvantages are: centric arrangement of the reinforcement, friction induced at bearing plates and difficulties with gripping of the reinforcement at load application (end anchorage). In order to minimize presented disadvantages, modified pull-out tests have been proposed. The issue of eccentricity was addressed by de Lorenzis et al. (2002) with a C-formed specimen (Figure 3). It consists of a C-shaped concrete block (edge size of 300 mm) with a square groove in the middle for embedment of the NSM reinforcement. It is generally considered that beam pull-out tests are more representative for bond behaviour of real members, while the effect of member curvature (deflection) cannot be considered.

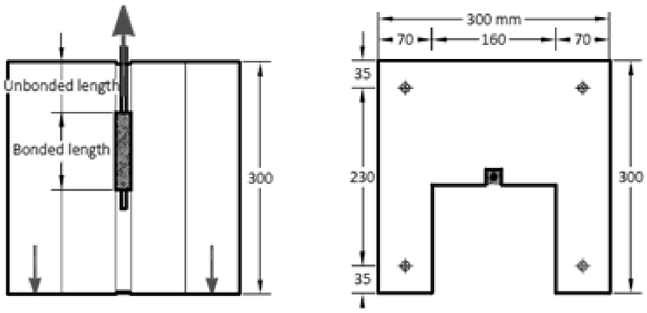

Figure 3. Schematic representation of C-shaped pull-out test.

2.3.3 Double tension-tension test

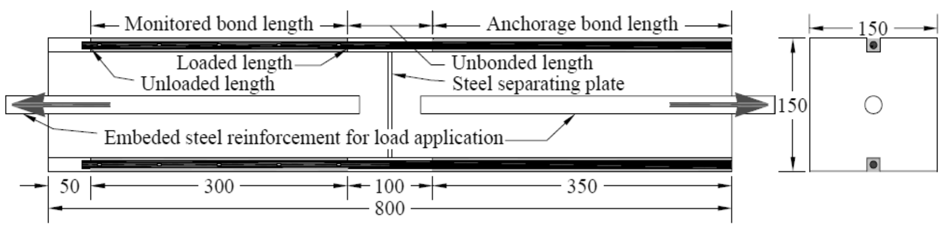

Figure 4. Schematic representation of double tension-tension test.

The prismatic specimen (Figure 4) is weakened by a steel plate in the middle. FRP strips can be mounted on two opposite sides. The gripping of specimens is possible by embedded steel bars at both ends. The specimens are loaded in tension at both ends. Tensile loading of the embedded steel bars which are anchored in the specimen induce radial stresses. This could affect the capacity of the studied FRP interaction especially in case of tests on NSM reinforcements. Radial stresses could particularly influence the bond behaviour at the unloaded side in special at ultimate load level. Internal reinforcement around the embedded steel bar or two steel bars instead of one can be used to overcome this issue.

3 THE ADVANCED PULL-OUT TEST METHOD WITH L-SHAPED

The test methods described in the previous chapter have some disadvantages, which can make the investigation of the bond behaviour rather time consuming, difficult to carry out (more possibilities for errors) or expensive.

To study the force transfer between the FRP reinforcement and the surrounding concrete in case of NSM strengthening method, an advanced pull-out specimen was developed at the Budapest University of Technology and Economics (Balázs et al, 2008). The authors' aim was to develop a test method which can overcome the above mentioned difficulties. After a thoughtful planning and numerous experimental prototypes, the final design was chosen. The characteristics of the advanced L-shaped pull-out test are presented in the following subchapters.

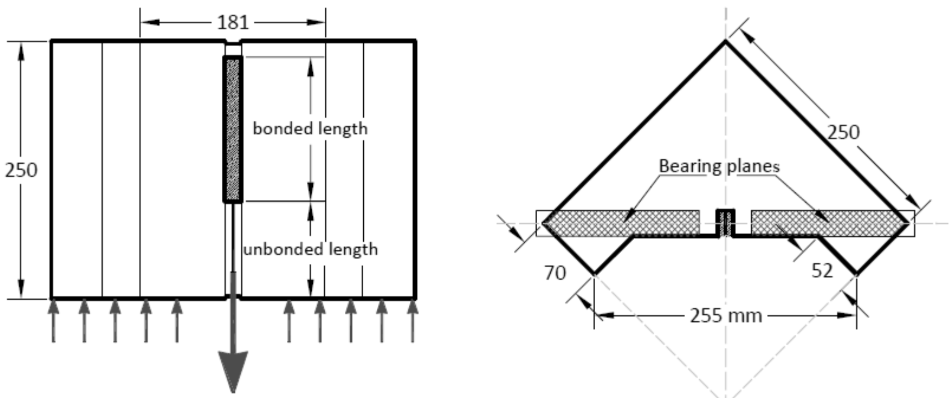

Figure 5. Developed L-shaped pull-out specimen.

The specimen shown in Figure 5 was designed to reduce eccentricities during loading of a single reinforcement. The L-shaped specimen is formed from a cubic specimen of 250 mm sides with cut-outs. The testing plane is parallel to one of the diagonal planes and it is shifted in order to have the longitudinal axis of the reinforcement as close as possible to the diagonal plane. The thickness of the specimen is the highest in the second diagonal plane (perpendicular to the first diagonal plane), this offers high stiffness to the specimen in the plane which is weakened by the groove and is usually highly stressed by the bond stresses perpendicular to the reinforcement. The flappers increase the stability and help handling of the specimen. The special L-shaped form of the specimen enabled proper view of the supposed failure surface, and it also provided the possibility of measuring the displacement on both loaded and unloaded ends (Szabó, 2008; Szabó et al, 2012).

The maximum achievable embedment length with the L-shaped specimen is 210 mm.
Summarizing the advantages of the newly developed specimen (Szabó, 2013):

- possibility to perform centric pull-out of NSM reinforcement;

• maximized testing plane (180x250 mm) in comparison to the specimen size, allowing undisturbed crack propagation with enough stiffness perpendicular to the testing plane;
• good access to the testing plane for groove cutting, for mounting the LVDTs, and for proper view on possible cracks;
• able to perform bond tests with various parameters;
• manageable specimen size;
• simple enough to perform high number of tests.

4 TEST RESULTS

In the following the experimental results will be presented. The same type of FRP rebar (CFRP, spirally woven and sand coated, 6 mm diameter) was used both for the L-shaped and for the double tension-tension tests so the result can be compared.

The studied bond length was 175 mm for the L-shaped specimen and 300 mm for the tension-tension specimen. The local bond behaviour should not be influenced by this aspect as the effective anchorage length for NSM reinforcements is considered to be shorter than 175 mm.

4.1 Test results obtained by using the L-shaped specimen

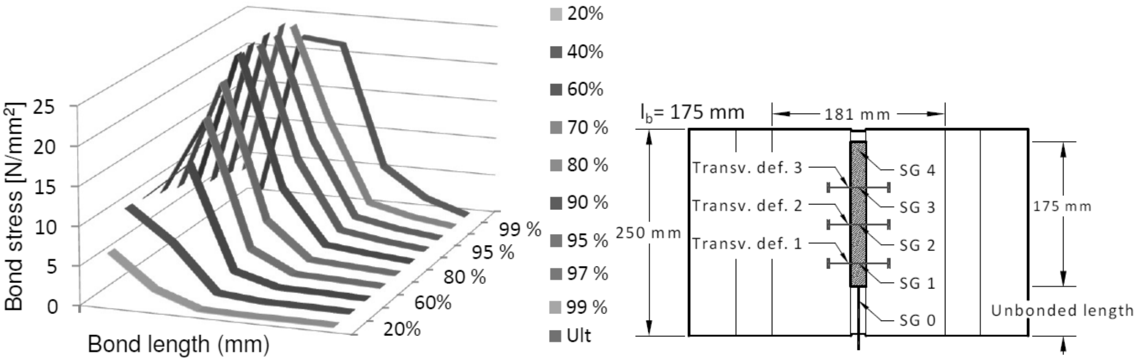

Figure 6. Bond stresses along the bond length at different load levels by using the L-Shaped specimen.

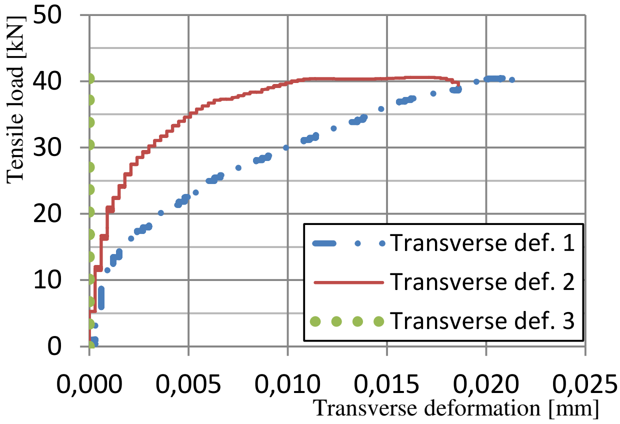

Figure 7. Tensile load - transverse deformation diagrams.

Figure 6 shows the development of the bond stress along the bond length, for the L-shaped specimen. The same is shown for the tension-tension specimen in figure 10. Results shown in Figure 6 can be compared to results shown in Figure 10. The maximum stresses are located at the side of load application until the shear resistance of the adhesive is reached (in cases were sufficient confinement of the reinforcement is assured). Thereafter, the gradual deterioration of the interaction starts. The maximum bond stresses move towards to the unloaded end. The pull out load measured using the L-shaped specimen was over 40 kN (bond length 175 mm) which is relatively high in comparison to the results measured with the tension-tension specimen were the failure load was 34.2 kN (bond length 300 mm).

Figure 7 indicates the transverse deformation of the L-shaped specimen during loading. As expected deformations were higher close to the loaded end (transverse def. 1), and it was negligible at the unloaded end. A good correlation can be observed between results shown in Figures 6 and 7. The bond stresses were especially high at the loaded end and almost zero at the unloaded end. In case of the advanced pull-out test the pull-out load, the deformations of five strain gauges and the slip at the loaded end were measured (results for slip measurement are not shown herein).

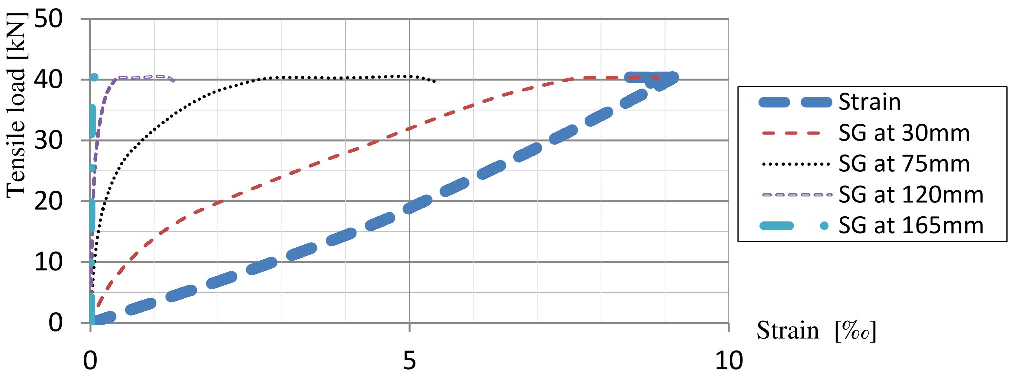

Figure 8. Tensile load – strain diagram at different strain gauges (at 30, 75, 120 and 165 mm along the bond length).

4.2 *Test results obtained by using the double tension-tension test specimen*

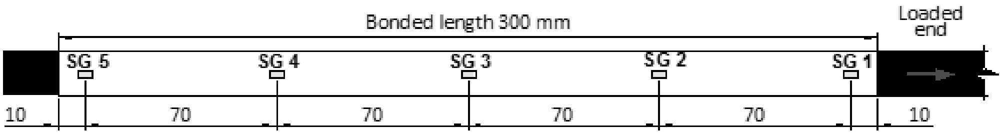

Figure 9. Strain gauge arrangement.

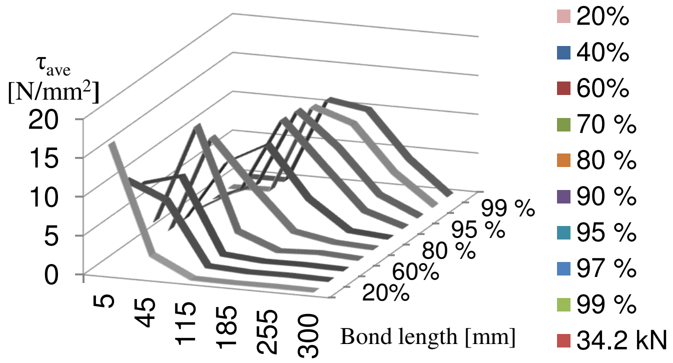

Figure 10. Bond stress-bond length diagram at different loads.

Strain gauges were glued to the reinforcements as shown in figure 9. Strain measurements along the bond length show in detail the development of bond stresses along the bond length. The strain gauge measurement are shown is Figure 8 and Figure 11.

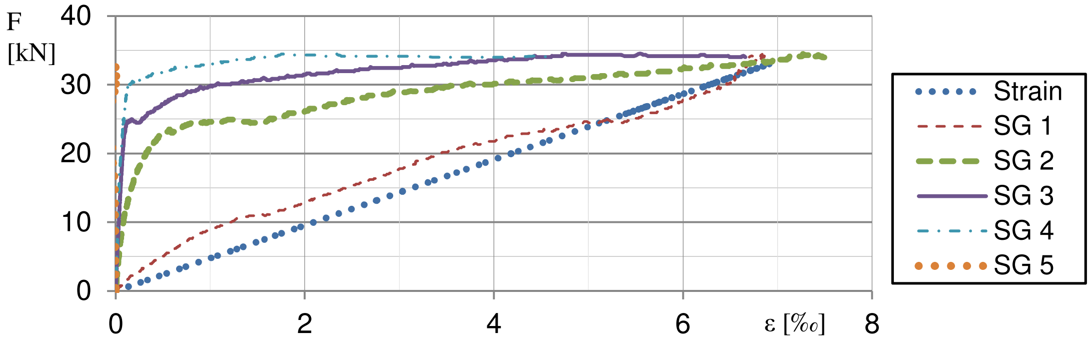

Figure 11. Load-strain diagrams.

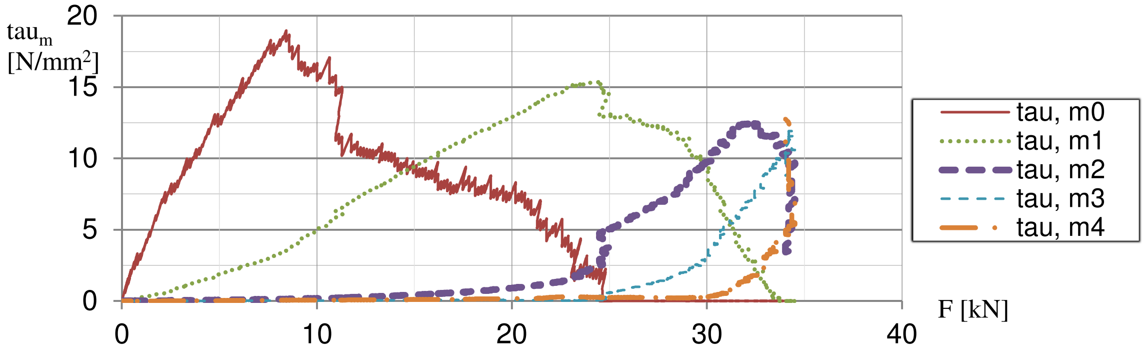

Figure 12. Tensile load – average bond stress (at different part of the embedded reinforcement) diagram.

The average bond stresses were calculated using the strain values, results are shown in figure 12.

5 COMPARISON OF THE RESULT FROM DIFFERENT TEST METHODS

Bond strength values obtained by the tension-tension specimen were for each of the studied reinforcement lower than measured using the L-shaped specimen (Figure 6 - 12). In order to give reliable information on bond capacity the highest value should be used. This value will be considered to be valid for optimal confinement conditions. This value can be afterwards corrected with reduction factors for each particular application (Szabó, 2008).

Measurements of the transverse deformations showed considerably high values for the tensile-tensile specimens over 1 mm in comparison to the maximum of 0.3 mm observed for the L-shaped specimen.

At the L-shaped specimen high values were recorded in the first part of the bond length and with low values at the second part. In contrary to this, when the tension-tension setup was used progressive failure was observed with a good mobilization of the bond capacity along the entire bond length.

6 CONCLUSIONS

The aim of this paper was to present an advanced and reliable test procedure for the experimental studies of bond behaviour of NSM reinforcements. Authors developed an advanced L-shaped specimen for pull-out testing of the NSM reinforcements. Details of the specimen and the experimental procedure as well as advantages of the L-shaped specimen are given in Chapters 3 and 4.

With the newly developed L-shaped test specimen it is possible to perform centrical pull-out test in displacement controlled mode by measuring the applied load and relative displacement on both loaded and unloaded ends. Test results obtained with the L-shaped specimen were compared to results obtained by a tension-tension specimen. Bond strength values obtained by the tension-tension specimen was for each of the studied reinforcement lower than measured using the L-shaped specimen.

7 ACKNOWLEDGEMENTS

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