FRP RRT: Technical Specifications

(version 2008-08-13)

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ROUND ROBIN TESTS

1 INTRODUCTION

This initiative relates to an international round robin testing (RRT) for FRP strengthening conducted in the framework of the EN-CORE project (Marie Curie Research Training Network) and fib TG 9.3 (International Federation for Structural Concrete Task Group 9.3) .

The objectives of this FRP RRT are:

1) Enable comparisons of results between different laboratories;
2) Enable simple comparisons between the properties of the different products that will be tested using the same test set-up;
3) Assisting international committees working in the field of standardization for assessing the product properties by simple tests;
4) Stimulating the development of standard test methods.

Other indirect benefits expected is the familiarization of researchers with the range of FRP products available in the global market and drawing attention to the international efforts for development of guidelines and standardisation.

Round Robin Tests consist in:

1. Tensile testing of FRP laminates and rebars
   RRT 1.1 Tensile testing of bars for internal reinforcement.
   RRT 1.2 Tensile testing of rebars for NSM (Near Surface Mounted).
   RRT 1.3 Tensile testing of laminates for EBR (External Bonded Reinforcement).
2. FRP- concrete bond testing of EBR and NSM
   RRT 2.1 Bond test for EBR laminates.
   RRT 2.2 Bond test for NSM rods/strips.

Tensile tests of FRP laminates and rebars (RRT 1.1; RRT 1.2; RRT 1.3) aim to examine the tensile properties (strength, failure strain and modulus of elasticity) of FRP. The obtained tensile properties can be used for material specification, quality control and structural design and analysis.

FRP-concrete bond testing of EBR and NSM (RRT 2.1 and RRT 2.2) aim to examine the bond properties between the FRP materials and concrete and the bond properties of the two different techniques tested.

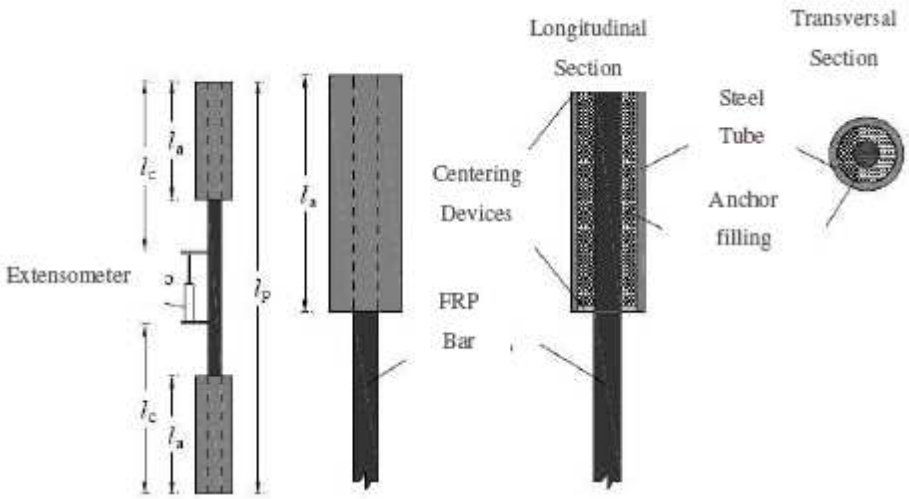
The specifications in this document are based on the following standard and guidelines:

- EN ISO 527-5: Determination of tensile properties- Part 5: test conditions for unidirectional fiber reinforced plastic composites.
- ASTM D3039: Standard test method for tensile properties of polymer matrix composite materials.
- ACI 440.3R 04 “Guide Test Methods for Fiber- reinforced Polymers for Reinforcing or Strengthening Concrete Structures”.
- JSCE “Recommendation for design and construction of concrete structures using continuous fiber reinforcing materials”.

All organizational details are posted on the website http://cigroup.shef.ac.uk/encore/rrt and presented to the relevant committees.

2 TENSILE TESTS ON FRP BARS (RRT 1.1 AND RRT 1.2)

2.1 Test set-up



Test set up

Technical notes

1. The development of the tensile test procedure aims to guarantee the fibers rupture in the test length of the bar, avoiding all possible factors that could cause a different failure type.
2. The preferred anchorage system consists of steel pipe filled with either pure polymer resin or a 1:1 mixture by weight of resin and clean sand or an expansive cement grout. Recommended detailing of the tube anchorage is given in ACI 440.3R. Alternative anchorage systems (taken into account item 1) may be applicable depending on the available laboratories infrastructures and experience.
3. A testing machine will be used with a loading capacity in excess of the tensile capacity of the test specimen. The rate of loading (displacement rate or load rate) will be constant during the test, and should be such that the specimen fails in 1 to 10 min. A displacement rate of maximum 2 mm/min or a loading rate of 22 kN/min is suggested. Displacement controlled loading is preferred.
4. For tensile tests on FRP strips for NSM the test setup is the same of that discussed below for FRP laminates (section 3).

2.2 Bar details

- Overall length (l_p) must be 40 times the bar diameter (d_b) plus 2 times the anchorage length (l_a) $l_p \geq 40\ d_b + 2\ l_a$.
- Anchorage length (l_a) will be at least 200 mm or greater in order to avoid that specimen fails at or slips out of an anchoring section.
- The bars will be tested in minimum of 5 samples for each diameter.

Technical notes

1. The bar length will be supplied with the length suggested in the following table.

Table – Bar lengths

Diameter (mm)	Length ($40d_b$) (mm)	Anchorage length (mm)	Total length(*) (mm)
6	240	200	700
8	320	200	800
9	360	200	800
10	400	200	800
12	480	200	900
14	560	200	1000
16	640	200	1100
19	760	200	1200
20	800	200	1200
22	880	200	1300
(*) Taken as l_p and rounded to upper 100 mm			

2. Five samples are needed to account for material variability.

2.3 Measurements

- Dimensional measurements.
- Tensile load will be measured by a load cell or pressure tranducer.
- To determine the modulus of elasticity and ultimate strain of the test specimen, the extensometer or LVDT will be mounted in the centre of the test section at a distance from the anchorage of at least 8 times the diameter of the FRP bar.
- The extensometer or LVDT shall be properly aligned with the direction of tension.

Technical notes

1. The nominal characteristics of the bar will be supplied by the manufacturers.

2.4 Presentation of results

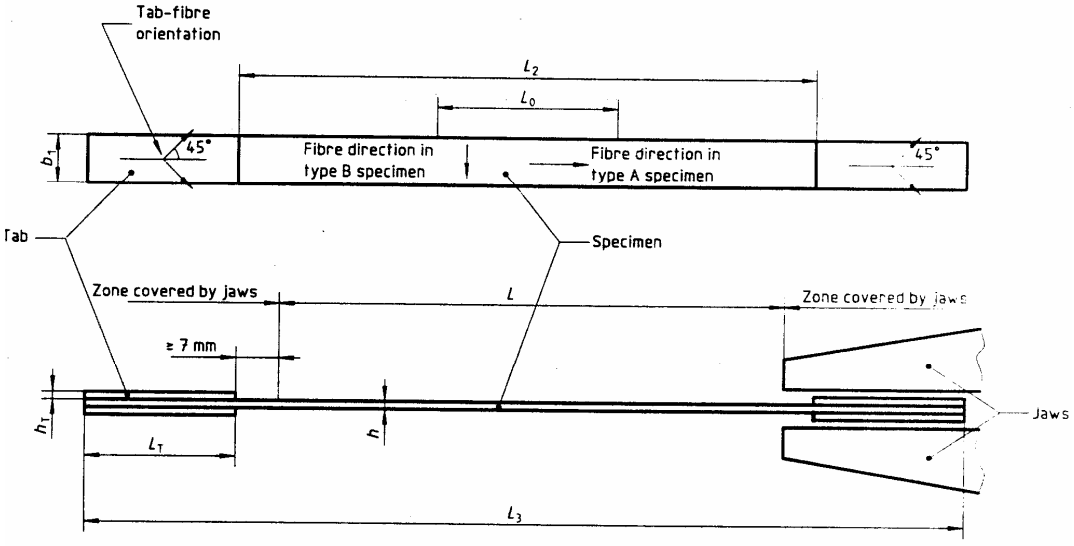
The test report will include the following items:

- Type of fiber and fiber binding material, and volume ratio of fiber, as reported by the manufacturer.
- Numbers or identification marks of test specimens, date of test, test temperature, and loading rate.
- Designation, equivalent diameter, and cross sectional area as determined in ACI 440-3R.
- Details of specimen conditioning including: environment, temperature, humidity, and duration.
- Ultimate tensile strength for each test specimen, means and standard deviation for ultimate tensile capacity, and tensile strength.
- Tensile modulus of elasticity for each test specimen, and means and standard deviations. The secant modulus is reported both as $E_{1\text{-}3‰}$ (taken between 1‰ and 3‰) and $E_{20\text{-}60\%}$ (taken between 20% and 60% of the ultimate load).
- Tensile strength and modulus of elasticity should be calculated with respect to the mean cross sectional area and/or the equivalent (nominal) cross sectional area. The considered cross sectional area should be clearly mentioned.

- Ultimate strain for each test specimen, means, and standard deviation.
- Stress (load) – strain curve for each test specimen.
- Failure aspect. A description, with photographs and sketches if necessary, of the post failure appearance of each specimen. Report anomalous failure modes observed during testing or anomalous post-failure appearances of any specimens.
- If maximum load or strain differs from the ultimate load or strain, both are reported.

3 TENSILE TESTS OF LAMINATES FOR EBR (RRT 1.3)

3.1 Test set-up



Test set up

Technical notes

1. The development of the tensile test procedure aims to guarantee the fibers rupture in the test length of the coupon, avoiding all possible factors that could cause a different failure type.
2. To provide appropriate anchorage during testing rectangular tabs (steel or E-glass materials) will be used at both ends of each specimen in order to diffuse clamping stresses. Recommended detailing of the tube anchorage is given in EN ISO 527-5. The tabs will be bonded to the surface of the specimen using a high-elongation (tough) adhesive system. Alternative anchorage systems (taken into account item 1) may be applicable depending on the available laboratories infrastructures and experience.
3. Failure or pullout at an anchoring section should be disregarded and the test findings should be based solely on test specimens that fail in the gauge section.
4. A testing machine will be used with a loading capacity in excess of the tensile capacity of the test specimen. The rate of loading (displacement rate or load rate) will be constant during the test and should be such that the specimen fails in 1 to 10 min. A displacement rate of maximum 2 mm/min or a loading rate of 22 kN/min is suggested. Displacement controlled loading is preferred.

3.2 Specimen details

- Overall length (L_3) = 250 mm.
- Distance between end tabs (L_2) = 150 mm.
- Specimen width (b_1) = 15 mm.
- Specimen thickness (h) = product thickness.
- Initial distance between grips (L) = 136 mm
- Length of end tabs (L_T) = 50 mm
- Thickness of end tabs (h_T) = 0,5 ÷ 2 mm

- Specimens will be tested in minimum 5 samples for each standard product.

Technical notes

1. Five samples are needed to account for material variability in accordance to the international standard test method EN ISO 527-5.
2. FRP specimens shall be prepared (e.g. to glue the anchorage tabs or to make test coupons) as specified by the manufacturers.
3. Test coupons for wet lay up type of FRP shall be prepared in the laboratory on teflon paper (or similar to avoid adhesion with the substrate) following the same procedure as specified by the manufacturers for real applications.
4. Test coupons shall be cut to size using an appropriate table saw. Care should be taken to ensure that the specimen is flat and not damaged by the cutting operation.

3.3 Measurements

- Dimensional measurements.
- Tensile load will be measured by a load cell or pressure transducer.
- Strain may be determined by means of strain gauges glued at the centre of the sample.

Technical notes

1. The nominal characteristics of the laminates will be supplied by the manufacturers.

3.4 Presentation of results

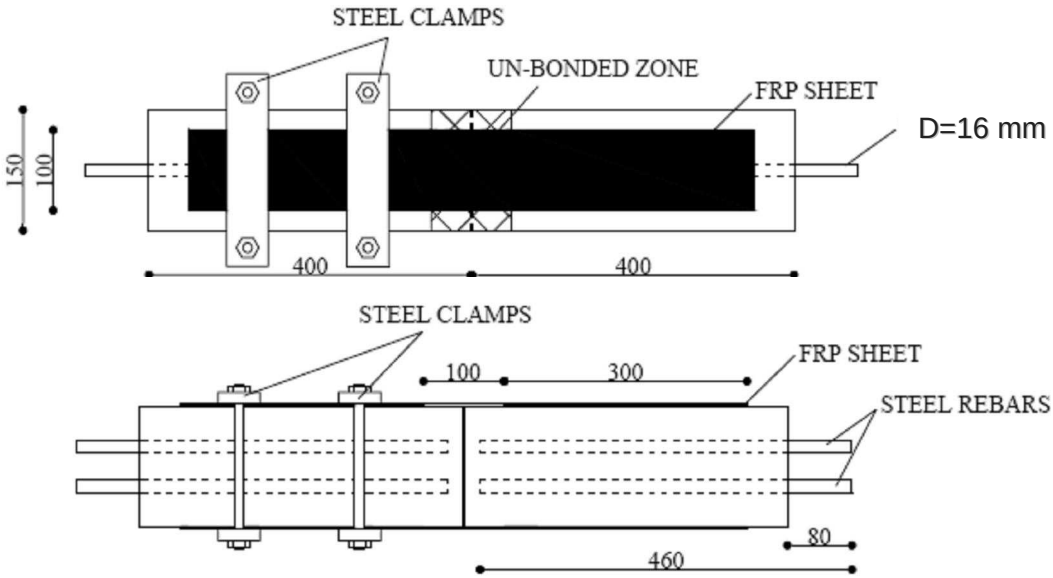
The test report will include the following items:

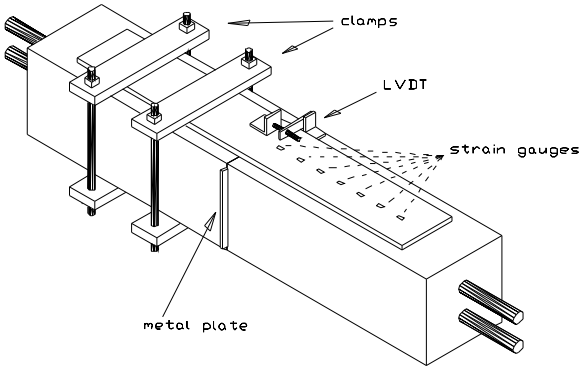
- Type of fiber and fiber binding material, and volume ratio of fiber, as reported by the manufacturer.
- Numbers or identification marks of test specimens date of test, test temperature, and loading rate.
- Specimen dimensions and cross sectional area.
- Details of specimen conditioning including: environment, temperature, humidity, and duration.
- Ultimate tensile strength for each test specimen, means and standard deviation for ultimate tensile capacity, and tensile strength.
- Tensile modulus of elasticity for each test specimen, and means and standard deviations. The secant modulus is reported both as $E_{1\text{-}3‰}$ (taken between 1‰ and 3‰) and $E_{20\text{-}60\%}$ (taken between 20% and 60% of the ultimate load).
- Tensile strength and modulus of elasticity should be calculated with respect to the mean cross sectional area and/or the equivalent (nominal) cross sectional area. The considered cross sectional area should be clearly mentioned.
- Ultimate strain for each test specimen, means, and standard deviation.
- Stress (load) – strain curve for each test specimen.

- Failure aspect. A brief description, with photographs and sketches if necessary, of the post failure appearance of each specimen. Report anomalous failure modes observed during testing or anomalous post-failure appearances of any specimens.
- If maximum load or strain differs from the ultimate load or strain, both are reported.

4 BOND TEST FOR EBR LAMINATES (RRT 2.1)

4.1 Test set-up





Test set up

Technical notes

1. The concrete specimen (150x150x800) is formed by two concrete prisms (150x150x400).
2. The two prisms are only connected through the surface bonded FRP reinforcement.
3. On one side of the test specimen extra fixation of the FRP is provided (e.g. by means of clamps) to force the bond failure on the other side.
4. A thin metal plate separates the two concrete prisms. The height of this plate is at both sides 15 mm less than the height of the prisms, so that both prisms remain aligned during specimen manipulation and application of the FRP.
5. To be able to connect the specimen to the universal tensile testing machine, two steel rods with a diameter of 16 mm and a free length of 80 mm will be embedded in the concrete prisms. Careful attention will be given to the alignment of internal rebars, by means of formwork holders.

6. Tests will be carried out in a tensile machine with a capacity in excess of the tensile capacity of the test specimen. The rate of loading (displacement rate or load rate) will be constant during the test. A displacement rate of 0,1 mm/min or a loading rate of 6 kN/min is suggested. Displacement controlled loading is preferred.
7. Test will be performed at least on 3 specimens.
8. Depending on the laboratory equipment the test set-up may be adapted, as long as the dimensional details are respected, special care is considered with respect to alignment, and the bond test being performed in a tension-tension situation.

4.2 Laminate details

- Laminate length = 700 mm, cross-section as delivered by the manufacturer. Width of 100 mm is preferred.
- The laminates will be supplied in minimum 6 samples (2 side faces for each specimen) for each standard product and with a length of 700 mm.

Technical notes

1. The FRP reinforcement is left un-bonded over a central zone of 100 mm (where the two concrete prisms connect each other). Special care is needed to prevent gluing in this zone.
2. The FRP reinforcement will be glued on two opposite sides of the concrete specimen, taking into account the application procedures as provided by the suppliers.
3. The bonded length equals 300 mm for each prism, which is somewhat higher than the maximum transfer length needed to develop the full anchorage force which can be built up by the FRP-concrete interface. This length has been chosen based on fracture mechanics analysis according to fib Bulletin 14.
4. FRP specimens shall be prepared (e.g. to glue to the concrete, to perform the wet lay-up procedure, etc.) as specified by the manufacturers.

4.3 Concrete

- Target concrete cylinder strength f_{cm}= 30 MPa
- Days after which the specimen can be tested ≥ 28 days
- Concrete composition and properties of the fresh and hardened concrete to be reported:
    - Slump, flow, density of the fresh concrete
    - Compressive strength derived from at least the test of 3 cylinders dia. 150 mm x 300 mm. If 3 cubes (150 x 150 x 150 mm³) can be tested, data need to be reported as well.
    - The secant modulus of elasticity by compressive test on 1 cylinder (dia. 150 mm x 150 mm).
    - The tensile strength by 3-point bending tests on 3 prism (150 x 150 x 600 mm³) with span length of 500 mm and by splitting test on the remaining halves of the prisms used for the bending tests. Alternative to the prisms, three cylinders (dia. 150 mm x 300 mm) can be tested to give (only) the tensile strength according to the Brazilian splitting test.

4.4 Measurements

- Dimensional measurements.
- Tensile load will be measured by a load cell or pressure transducer.
- The relative displacement between the FRP reinforcement and the concrete will be recorded with one LVDT per monitored side (2 LVDTs), fixed to the concrete and directly connected to the FRP reinforcement at the loaded end (at the location of the transition between the central un-bonded and the bonded zone).
- The strains along the laminate will be obtained from minimum 5 strain gauges glued to the laminate. The gauges will be applied at 10, 80 ,150, 220 and 290 mm from the end of the laminate on both sides.

4.5 Presentation of results

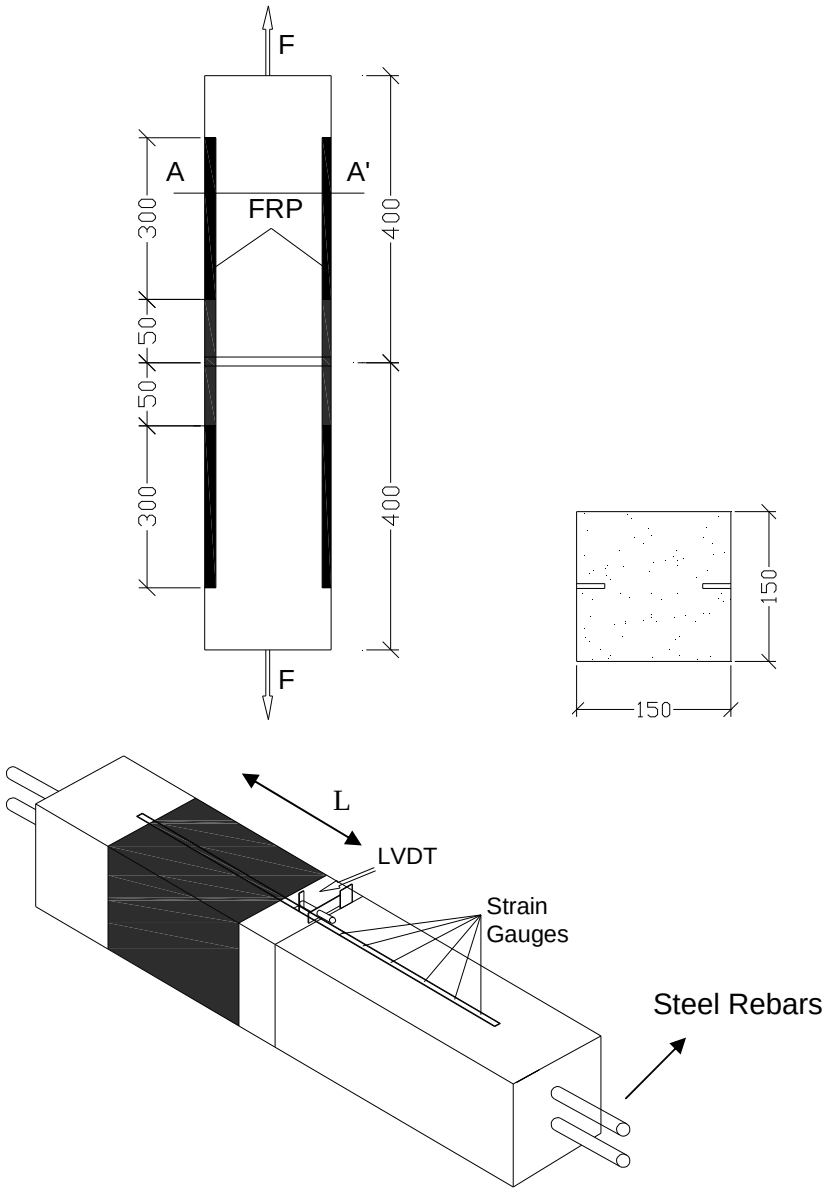
The test report will include the following items:

- Type of fiber and fiber binding material, and volume ratio of fiber, as reported by the manufacturer.
- Concrete details (section 4.3). Properties of the hardened concrete are reported at 28 days and (except for the modulus of elasticity) at age of testing.
- Numbers or identification marks of test specimens, date of test, test temperature, and loading rate.
- Specimen dimensions.
- Nominal characteristics of FRP as provided by manufacturer: FRP thickness, cross-section, tensile strength, modulus of elasticity, ultimate strain.
- Details of specimen conditioning including: environment, temperature, humidity, and duration.
- Failure load for each test specimen, means, and standard deviation. Maximum strain in the un-bonded zone at failure load.
- Average bond capacity for each test specimen, means, and standard deviation.
- Stress (load) – strain curve, measured by strain gauges, for each test specimen.
- Stress (load)- slip curve, measured by LVDTs, for each test specimen.
- Failure aspect. A description, with photographs and sketches if necessary, of the failure aspect of each specimen (in particular of the debonding surface).
- If maximum load differs from the ultimate load, both are reported.

5 BOND TEST FOR NSM RODS/STRIPS (RRT 2.2)

For testing efficiency and comparison reasons, RRT 2.2 is taken similar to RRT 2.1, considering bond testing in a tension-tension situation. Pull-out bond testing, similar to classical pull-out testing of internal rebars, is hence not considered in the framework of this RRT.

5.1 Test set-up



Test set up

Technical notes

1. The concrete specimen (150x150x800) is formed by two concrete prisms (150x150x400).
2. The two prisms are only connected through the FRP reinforcement.
3. On one side of the test specimen extra fixation of the FRP will be provided (e.g. by means of an additional FRP sheet (L= 300 mm) or extending the bond length to all the concrete prism length) so to force the bond failure on the other side.

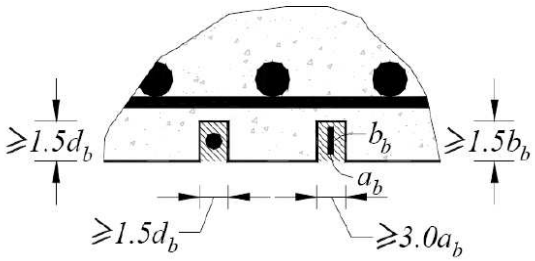
4. To be able to connect the specimen to the universal tensile testing machine, two steel rods with a diameter of 16 mm and a length of 80 mm will be embedded in the concrete prisms.
5. Tests will be carried out in a tensile machine with a capacity in excess of the tensile capacity of the test specimen. The rate of loading (displacement rate or load rate) will be constant during the test. A displacement rate of 0,1 mm/min or a loading rate of 6 kN/min is suggested. Displacement controlled loading is preferred.
6. Test will be performed at least on 3 specimens.
7. Depending on the laboratory equipment the test set-up may be adapted, as long as the dimensional details are respected, special care is considered with respect to alignment, and the bond test being performed in a tension-tension situation.

5.2 Rod/strip details

- The NSM elements will be supplied in minimum 6 samples (2 side faces for each specimen) for each standard product and with a length of 700 mm.

Technical notes

1. The FRP reinforcement is left un-bonded over a central zone of 100 mm (where the two concrete prisms connect each other).
2. The FRP reinforcement will be bonded, into the grooves on two opposite sides of the concrete specimens, with epoxy or repair mortar taking into account the application procedures as provided by the suppliers.
3. Unless stated otherwise by the manufacturer, the groove dimensions are related to the rods/strip dimensions, as follows:



Parretti, R., Nanni, A., Strengthening of RC members using near-surface mounted FRP composites: Design Overview, Advances in structural engineering, Vol. 7, No.5, 2004

5.3 Concrete

- Target concrete cylinder strength f_{cm}= 30 MPa
- Days after which the specimen can be tested ≥ 28 days
- Concrete composition and properties of the fresh and hardened concrete to be reported:
  - Slump, flow, density of the fresh concrete
  - Compressive strength derived from at least the test of 3 cylinders dia. 150 mm x 300 mm. If 3 cubes (150 x 150 x 150 mm³) can be tested, data need to be reported as well.
  - The secant modulus of elasticity by compressive test on 1 cylinder (dia. 150 mm x 150 mm).

- The tensile strength by 3-point bending tests on 3 prism (150 x 150 x 600 mm³) with span length of 500 mm and by splitting test on the remaining halves of the prisms used for the bending tests. Alternative to the prisms, three cylinders (dia. 150 mm x 300 mm) can be tested to give (only) the tensile strength according to the Brazilian splitting test.

5.4 Measurements

- Dimensional measurements.
- Tensile load will be measured by a load cell or pressure transducer.
- The relative displacement between the FRP reinforcement and the concrete will be recorded with one LVDT per monitored side (2 LVDTs).
- The strains along the laminate will be obtained from minimum 5 strain gauges glued to the rod/strip. The gauges will be applied at 10, 80 ,150, 220 and 290 mm from the end of the rod/strip on both sides.

5.5 Presentation of results

The test report will include the following items:

- Type of fiber and fiber binding material, and volume ratio of fiber, as reported by the manufacturer.
- Concrete details (section 4.3). Properties of the hardened concrete are reported at 28 days and (except for the modulus of elasticity) at age of testing.
- Numbers or identification marks of test specimens, date of test, test temperature, and loading rate.
- Specimen dimensions.
- Nominal characteristics of FRP as provided by manufacturer: FRP thickness, cross-section, tensile strength, modulus of elasticity, ultimate strain.
- Details of specimen conditioning including: environment, temperature, humidity, and duration.
- Failure load for each test specimen, means, and standard deviation. Maximum strain in the un-bonded zone at failure load.
- Stress (load) – strain curve, measured by strain gauges, for each test specimen.
- Stress (load)- slip curve, measured by LVDTs, for each test specimen.
- Failure aspect. A description, with photographs and sketches if necessary, of the failure aspect of each specimen (in particular of the debonding surface).
- If maximum load differs from the ultimate load, both are reported.

6 GENERAL REQUIREMENTS

6.1 Presentation of results

Test results must include:

1) All the details of the test setup, in particular if alterations are made with respect to the test set-up described in these specifications.
2) All requested results as described in the respective test procedures of this document.

Each participating laboratory is obliged to submit a FRP RRT testing report according to these guidelines (a template for this report will be made available). In addition each laboratory is free to publish the test results it has obtained (at its own laboratory) in the framework of this RRT, under the condition to present the test results in such a way to prevent direct comparison between material suppliers!

All the results from the laboratories will be collected and analysed. This will result in a final report presenting the overall results. A joint publication in a scientific journal will follow form this report, in addition to possible joint publications in conference proceedings.

6.2 Manufacturer obligations

FRP suppliers are obliged to:

1. To supply free of charge five (or more) samples[1] of each standard product they want to incorporate in the RRT to all participant laboratories.
2. To supply details of the mechanical characteristics.
3. To supply information regarding the handling of the materials.

Further details will be provided directly to the suppliers.

6.3 Laboratories obligations

Participating laboratories are obliged to:

1. Undertake the tests as specified by the Round Robin Test organisers.
2. Present the results in the specified format.
3. Use the results only for general comparisons during the Round Robin Testing and in no case for any other purposes.
4. Made the results available by the time specified by the organisers of the tests and in no case more than 4 months after receiving all the materials.

Laboratories that receive the materials but do not comply with their rules will be asked to refund the suppliers the expenses of materials and shipping.