EN-CORE/fib Round Robin Testing Initiative
Round Robin Tests 1.2
Tensile tests on bars/strip for NSM

J. A. O. Barros **I. G. Costa**

Report N.º 10-DEC/E-23

LEST-UM – Laboratório de Estruturas da Universidade do Minho, Department of Civil Engineering, University of Minho, Portugal

fib Task Group 9.3

University of Minho

1. RRT administration page

Institution:	University of Minho	
Laboratory:	Laboratório de Estruturas da Universidade do Minho (LEST-UM)	
Adress:	Azurém, 4800-085 Guimarães, Portugal	
Responsible research engineers:		
Inês Costa Joaquim Barros		ines.costa@civil.uminho.pt barros@civil.uminho.pt

Start date of testing:	16 Jan 2010
End date of testing:	17 Jan 2010
Report version date:	08 Feb 2010

Designation[1]	**Product name**	**Supplier**	**Participated in**[2]	**Date material received**
C–6–SC	Aslan 200	Hughes Brother	x	12 Jan 2009
B–6–SC	Rockbar	Magmatech	x	5 Mar 2009
B–8–SC	Rockbar	Magmatech	x	5 Mar 2009
C–1.4x10–S	CFK strip	S&P	x	7 Oct 2008
G–8–RB	ComBar	Schoeck	x	24 Oct 2008
C–2.5x15–S	Sika strip	Sika	x	29 Oct 2008
C–8–S	Sika bar	Sika	x	29 Oct 2008
C–10x10–S	STO bar	STO	x	7 Oct 2008
G–8–SW	ATP bar	ATP	nr	-

(1) For the remainder of the report only reference is made to the designation.

(2) Indicated for which products you participated in the RRT (x = participated, - = not participated, nr = intended to participate, but material not received)

FRP Properties (data by manufacturers)								
Name	**Type**	**Dim. [mm]**	**Length [mm]**	**A [mm^2]**	**f_f [MPa]**	**E_f [GPa]**	**ε_u [%]**	**Surface**
C–6–SC	Carbon	6	700	29.9	2068	124	1.7	Sand coated
B–6–SC	Basalt	6	700	29.9	-	50	-	Sand coated
B–8–SC	Basalt	8	800	50.2	-	50	-	Sand coated
C-1.4x10–S	Carbon	1.4x10	800	14	1850	165	-	Smooth
G–8–RB	Glass	8	800	50	1500	60	-	Ribbed
C–2.5x15–S	Carbon	2.5x15	800	37.5	3100	165	1.7	Smooth
C–8–S	Carbon	8	800	50.2	2800	155	1.8	Smooth
C–10x10–S	Carbon	10x10	1000	100	2000	155	1.5	Smooth
G–8–SW	Glass	8	800	29.9	-	-	-	Spirally wound

Bonding Agent for anchorage system property (data by manufacturers)	
Type	**StoPox SK 41**
Property	
Mixing ratio (resin:hardener)	4:1?
Pot life [min]	¿?
Density [kg/m^3]	¿?
Compressive strength [N/mm^2]	¿?
Tensile strength [N/mm^2]	¿?
Modulus of elasticity [N/mm^2]	¿?

Bonding Agent for anchorage system property (data by manufacturers)	
Type	**SikaDur 30 Normal**
Property	
Mixing ratio (resin:hardener)	3:1
Pot life [min]	90 at 20℃
Density [kg/m^3]	1650
Compressive strength [N/mm^2]	7 days: 70-80 (+10 ºC); 85-95 (+35 ºC)
Tensile strength [N/mm^2]	7 days: 24-27 (+15 ºC); 26-31 (+35 ºC)
Modulus of elasticity [N/mm^2]	12800

Bonding Agent for anchorage system property (data by manufacturers)	
Type	**Araldite Hardener 420**
Property	
Mixing ratio (resin:hardener)	10:4
Pot life [min]	60 at 25ºC
Density [kg/m^3]	1100 to 1200
Compressive strength [N/mm^2]	-
Tensile strength [N/mm^2]	-
Modulus of elasticity [N/mm^2]	-

In case different bonding agents have been used for the anchorage, clearly identify name and property

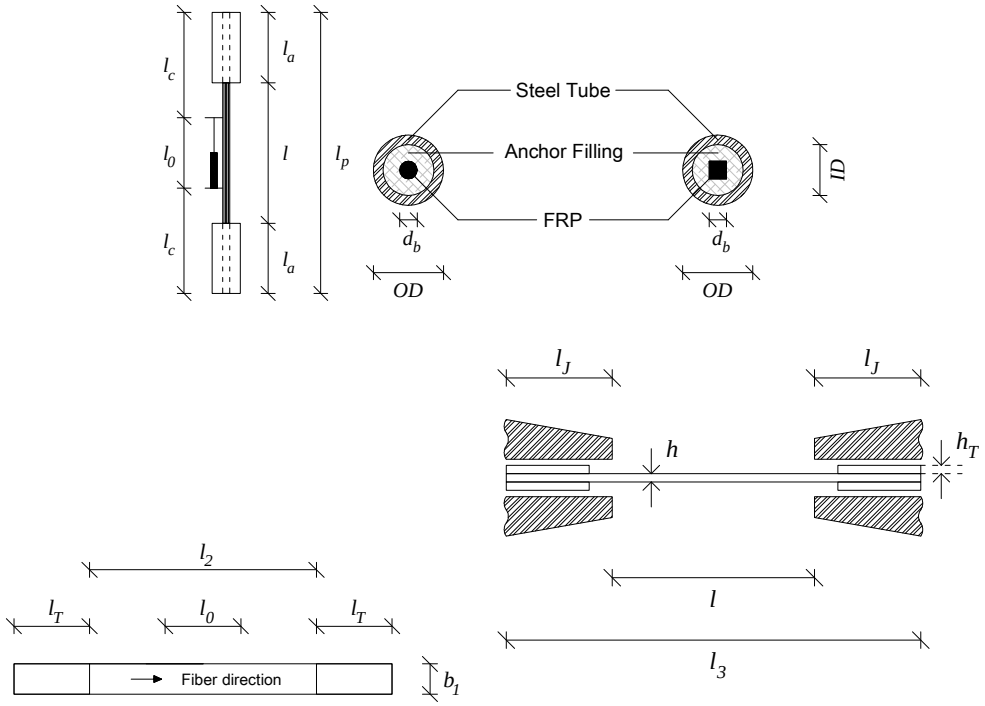
2. RRT test procedure feedback

The RRT prescription (Final draft of FRP RRT specifications , 13-Aug-08.) was followed	
- Exactly - With minor adjustments - With major adjustments - Was not followed	yes
The free end anchorage length was in some cases adjusted. It was expectable that higher cross sections would result in debonding of the FRP, if the adequate anchorage length was not provided.	
Your opinion about the RRT prescription	
- The testing is feasible to execute and the test method can be valuable for material characterisation (test standards). - Valuable but changes needed to make testing more feasible - Testing feasible but method not very valuable for material characterisation (test standards) - Neither feasible and valuable	yes yes no no
Please give further motivation on your opinion: The "RRT prescription", according to which the present tests were carried out, follows the recommendations available in existing standards	
Other comment and suggestions you want to make: The anchorage length adopted in the tests carried out was in the range 200 – 250mm, which is higher than the minimum value recommended in the "RRT prescription" (200 mm). However, as it will be commented in future sections, it was concluded that in certain FRP elements this anchorage length would have exceeded the 250 mm. It should be noted that ACI 440.3R indicates that the anchorage length should be function of the diameter of the bar.	

3. Test set-up

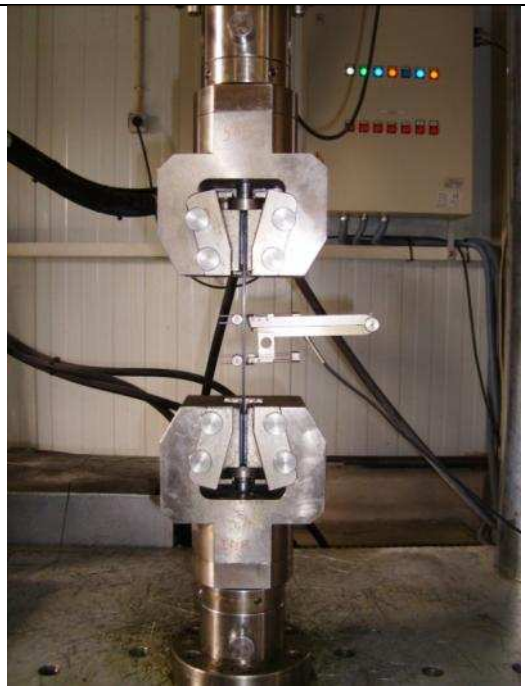
Test set-up - representation and dimensions:

The specimens were prepared according to RRT Test Procedure recommendations. The dimensions varied according to the type of rod/bar.



Specimen	l or l_2	l_a or l_T	l_0
	[mm]	[mm]	[mm]
C-6-SC	401	200	100
G-8-RB	385	200	100
B-6-SC	288	200	100
B-8-SC	386	200	100
C-1.4x10-S	150	50	50
C-2.5x15-S	150	50	50
C-8-S	305	240	100
C-10x10-S	451	250	100

Insert here one or more photo's illustrating the test set-up.



Test set-up - description:

The anchorage between the specimens and the testing machine was possible using the wedges available in fatigue frame.

Name	Anchorage	Filling material	ID [mm]	OD [mm]	l_a or l_T [mm]
C–6–SC	Steel	SikaDur 30 Normal	25	36	200
B–6–SC	Steel	SikaDur 30 Normal	25	36	200
B–8–SC	Steel	SikaDur 30 Normal	25	36	200
C-1.4x10–S	Steel	Araldite Hardener 420	-	-	50
G–8–RB	Steel	SikaDur 30 Normal	25	36	200
C–2.5x15–S	Steel	Araldite Hardener 420	-	-	50
C–8–S	Steel	SikaDur 30 Normal	25	36	240
C–10x10–S	Steel	StoPox SK 41	28	40	250
G–8–SW	-	-	-	-	-

Where:

ID = the internal diameter of the anchorage

OD= the external diameter of the anchorage

l_a *or* l_T *= the anchorage length*

Specimen preparation:

The anchorage system consists of a steel tube filled with an epoxy resin, or steel tabs glued to the FRP.

Name	1st Anchorage	2nd Anchorage	Testing	Days
C–6–SC	23 Oct 2009	26 Oct 2009	17 Jan 2010	83
B–6–SC	26 Oct 2009	27 Oct 2009	17 Jan 2010	82
B–8–SC	22 Oct 2009	23 Oct 2009	17 Jan 2010	86
C-1.4x10–S	22 Jan 2010	22 Jan 2010	3 Feb 2010	12
G–8–RB	20 Oct 2009	21 Oct 2009	17 Jan 2010	88
C–2.5x15–S	22 Jan 2010	22 Jan 2010	3 Feb 2010	12

C–8–S	21 Oct 2009	22 Oct 2009	17 Jan 2010	87
C–10x10–S	19 Oct 2009	20 Oct 2009	16 Jan 2010	88
G–8–SW	-	-	-	-

Testing machine:
Fatigue Frame of +/- 1000 kN. (The geometric characteristics of the wedges adopted to fix the FRP elements to the grips of the machine depended on the type of FRP element.)
Testing machine control:
Displacement control: 2 mm/min.
Instrumentation - representation and locations:
Only a clip-gauge was used, placed on the centre of the specimen. Image previously presented.

Remark: You can add separate rows in the above table if you want to report other aspects not mentioned.

4. Experimental results

Test results for the different specimen series are given as follows:

- Table X.1: test results in terms of nominal diameter, cross section area A, maximum applied load F_u, tensile strength f_f, ultimate strain ε_u, tangent modulus of elasticity $E_{f(0.1\text{-}0.3‰)}$, secant modulus of elasticity, $E_{f(20\%\text{-}50\%)}$ as well as the type of failure mode.
- Figure X.1: Photo(s) of the specimens after have been tested, and a short description of the failure mode.
- Figure X.2: Stress-strain diagrams.

being X the section number (4.1 till 4.9), corresponding to the different FRP materials.

4.1. Specimens *C-6-SC*

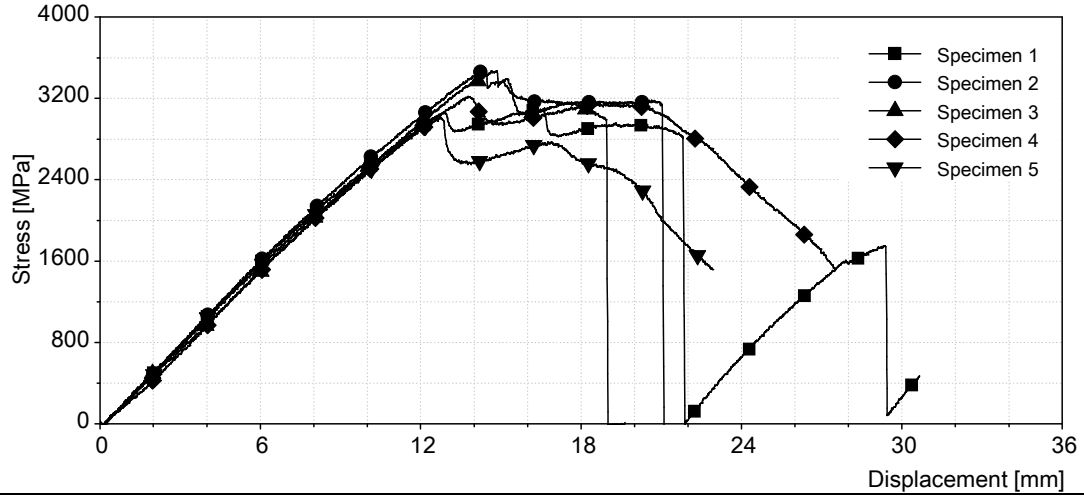
Table 4.1.1 – Tensile proprieties of C-6-SC specimens

Name	D [mm]	F_u [kN]	f_u [MPa]	ε_u [%]	$E_{(0.1\text{-}0.3\ ‰)}$ [GPa]	$E_{(ISO)}$ [GPa]	Failure mode
C-6-SC-1	6.00	95.45	3375.91	1.92	169.85	181.43	Anchorage
C-6-SC-2	6.00	106.06	3751.01	2.00	186.45	188.90	Anchorage
C-6-SC-3	6.00	106.15	3754.30	1.95	197.47	188.68	Anchorage
C-6-SC-4	6.00	99.08	3504.23	1.92	176.13	189.00	Debonding
C-6-SC-5	6.00	93.13	3293.65	1.80	179.46	187.30	Debonding
Mean	-	99.97	3535.82	1.92	181.87	187.06	-
St. deviation	-	5.99	211.69	0.07	10.58	3.22	-

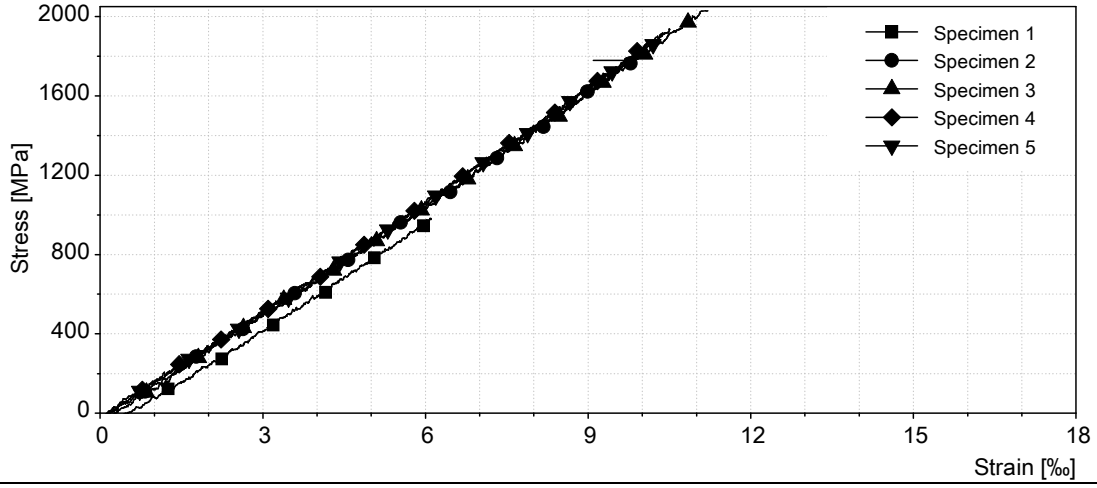
Failure aspects:
Anchorage: Failure of the FRP close to the anchorage
Debonding: Debonding of the FRP inside the adhesive

Figure 4.1.1 – Tested specimens

Description of failure mode: Since in general a significant slip of the bar inside the anchorage system was verified, a longer anchorage length seems recommended for future tests.



Stress vs displacement



Stress vs Strain

Figure 4.1.2

4.2. Specimens *B-6-SC*

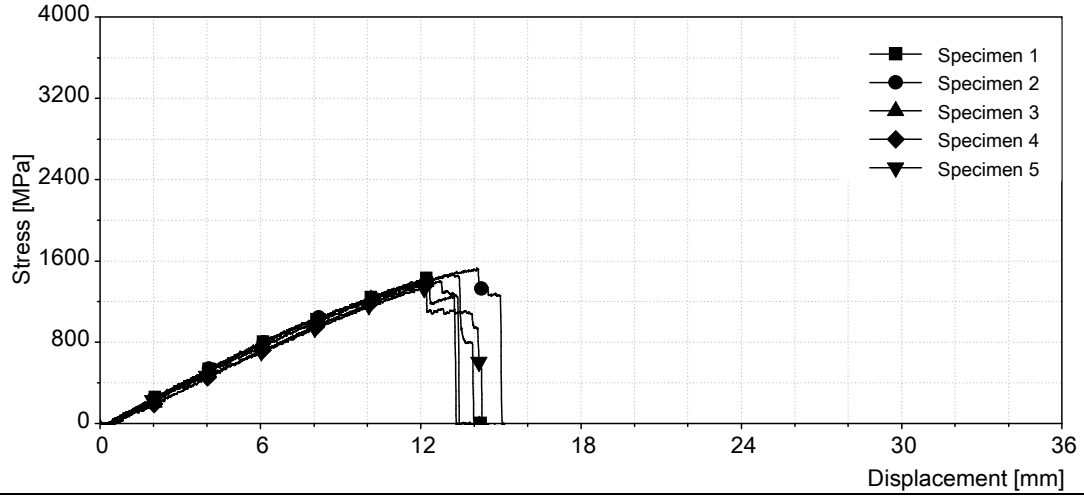
Table 4.2.1 – Tensile proprieties of B-6-SC specimens

Name	D [mm]	F_u [kN]	f_u [MPa]	ε_u [%]	$E_{(0.1\text{-}0.3\ ‰)}$ [GPa]	$E_{(ISO)}$ [GPa]	Failure aspect
B-6-SC-1	6.00	48.66	1720.86	3.13	56.79	53.43	LS
B-6-SC-2	6.00	51.26	1812.99	3.33	54.81	53.97	LS
B-6-SC-3	6.00	49.77	1760.34	3.15	57.34	54.58	LS
B-6-SC-4	6.00	46.98	1661.63	3.13	52.66	53.56	LS
B-6-SC-5	6.00	45.77	1618.86	2.93	55.16	55.26	LS
Mean	-	48.49	1714.93	3.13	55.35	54.16	-
St. deviation	-	2.18	77.11	0.14	1.84	0.76	-

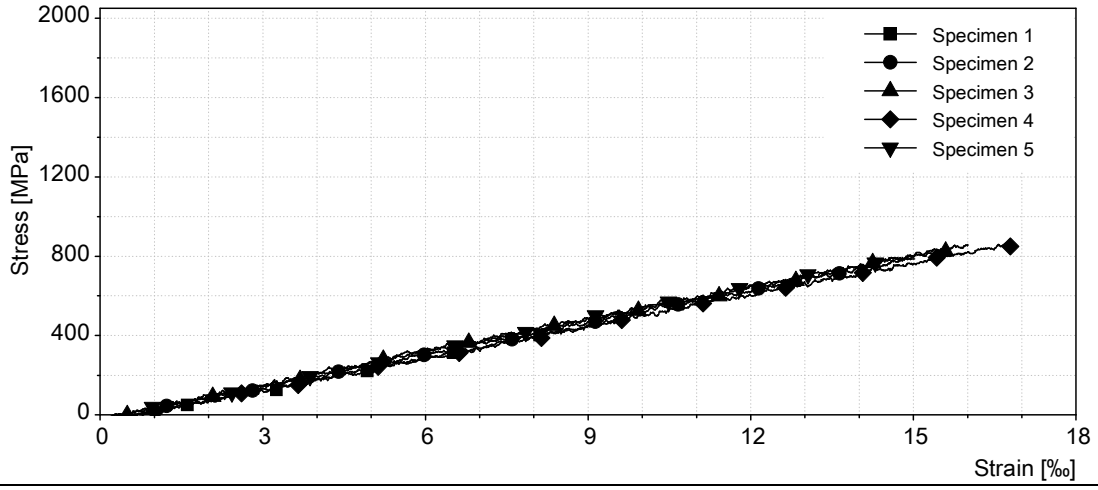
Failure aspects:
LS: longitudinal splitting and fibre fracture
PO: Pull-out bars

Figure 4.2.1 – Tested specimens

Description of failure mode: Explosive.



Stress vs displacement



Stress vs Strain

Figure 4.2.2

4.3. Specimens *B-8-SC*

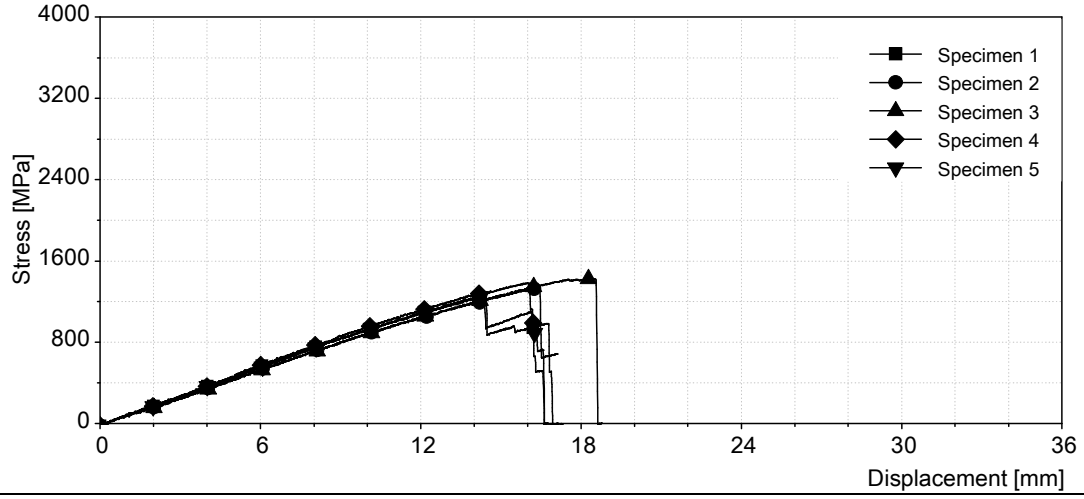
Table 4.3.1 – Tensile proprieties of B-8-SC specimens

Name	D [mm]	F_u [kN]	f_u [MPa]	ε_u [%]	$E_{(0.1\text{-}0.3\ ‰)}$ [GPa]	$E_{(ISO)}$ [GPa]	Failure aspect
B-8-SC-1	8.00	71.08	1414.03	2.61	55.39	52.95	LS
B-8-SC-2	8.00	75.36	1499.17	2.93	50.23	52.28	LS
B-8-SC-3	8.00	80.10	1593.56	3.01	53.27	52.49	LS
B-8-SC-4	8.00	77.59	1543.59	2.99	50.68	52.58	LS
B-8-SC-5	8.00	70.98	1412.18	2.64	54.49	52.71	LS
Mean	-	75.02	1492.51	2.84	52.81	52.60	-
St. deviation	-	4.01	79.81	0.20	2.29	0.25	-

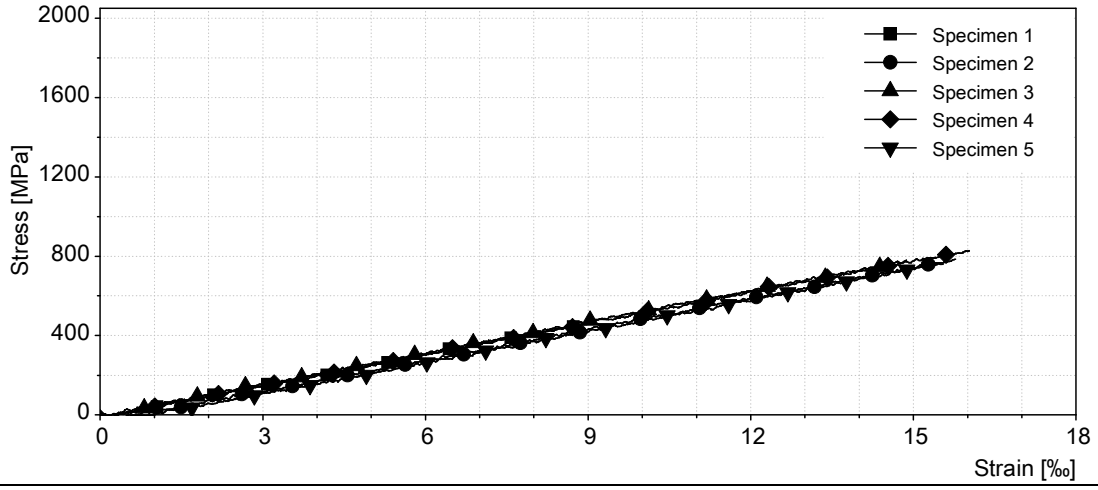
Failure aspects:
LS: longitudinal splitting and fibre fracture
PO: Pull-out bars

Figure 4.3.1 – Tested specimens

Description of failure mode: Explosive, although less than the corresponding bars of lower diameter.



Stress vs displacement



Stress vs Strain

Figure 4.3.2

4.4. Specimens *C-1.4x10-S*

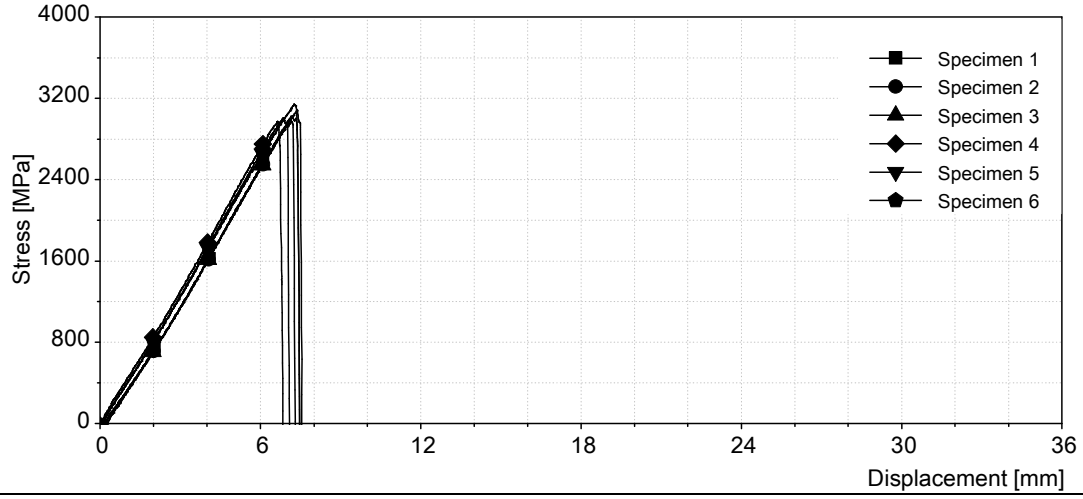
Table 4.4.1 – Tensile proprieties of C-1.4x10-S specimens

Name	D [mm]	F_u [kN]	f_u [MPa]	ε_u [%]	$E_{(0.1\text{-}0.3\ ‰)}$ [GPa]	$E_{(ISO)}$ [GPa]	Failure aspect
C-1.4x10-S-1	1.4x10	43.41	3100.41	1.84	168.09	-	LS
C-1.4x10-S-2	1.4x10	42.39	3028.20	1.83	155.73	176.33	LS
C-1.4x10-S-3	1.4x10	41.79	2984.97	1.80	160.46	172.37	LS
C-1.4x10-S-4	1.4x10	41.82	2986.87	1.74	166.92	175.64	LS
C-1.4x10-S-5	1.4x10	44.22	3158.85	1.86	163.40	177.45	LS
C-1.4x10-S-6	1.4x10	42.33	3023.45	1.77	165.56	175.70	LS
Mean	-	42.66	3047.12	1.81	163.36	175.50	-
St. deviation	-	0.96	68.90	0.04	4.61	1.89	-

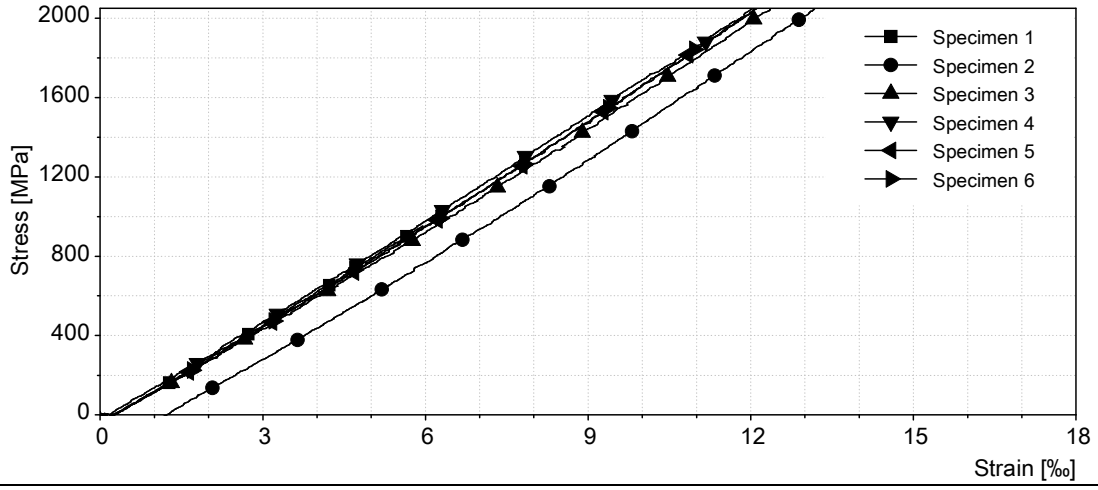
Failure aspects:
LS: longitudinal splitting and fibre fracture
PO: Pull-out bars

Figure 4.4.1 – Tested specimens

Description of failure mode: Noisy, but not so pronounced as occurred in the other FRP bars.



Stress vs displacement



Stress vs Strain

Figure 4.4.2

4.5. Specimens *G-8-RB*

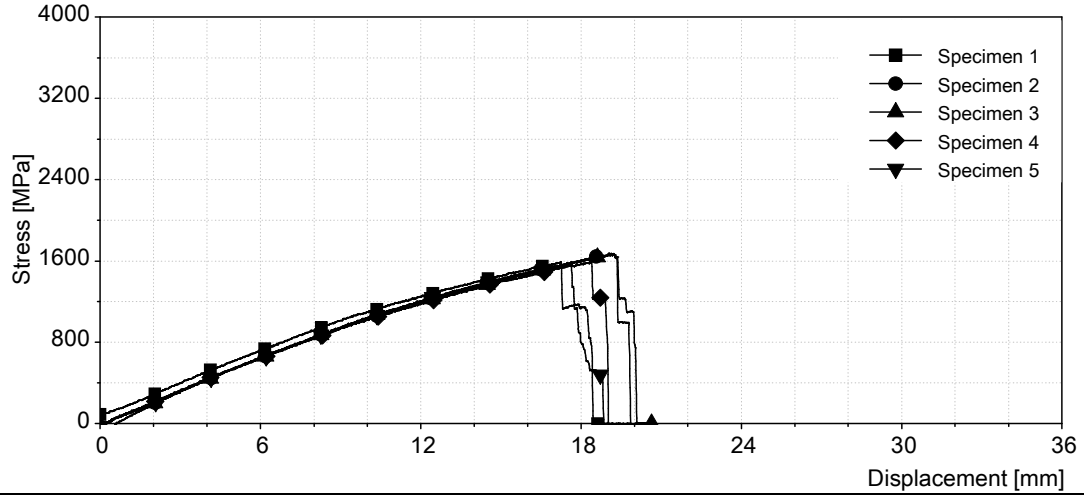
Table 4.5.1 – Tensile proprieties of G-8-RB specimens

Name	D [mm]	F_u [kN]	f_u [MPa]	ε_u [%]	$E_{(0.1\text{-}0.3\ ‰)}$ [GPa]	$E_{(ISO)}$ [GPa]	Failure aspect
G-8-RB-1	8.00	87.92	1749.03	2.54	69.08	68.59	LS
G-8-RB-2	8.00	92.29	1836.02	2.79	68.50	63.34	LS
G-8-RB-3	8.00	91.64	1823.06	2.77	68.21	63.37	LS
G-8-RB-4	8.00	87.73	1745.33	2.50	76.61	64.32	LS
G-8-RB-5	8.00	86.71	1724.97	2.58	70.06	63.95	LS
Mean	-	89.26	1775.68	2.64	70.49	64.71	-
St. deviation	-	2.52	50.22	0.14	3.49	2.20	-

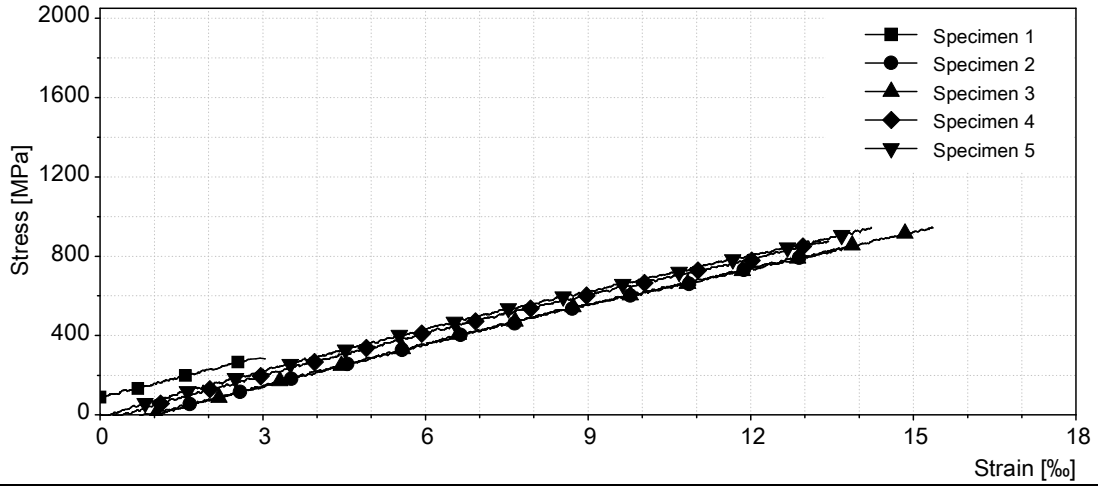
Failure aspects:
LS: longitudinal splitting and fibre fracture
PO: Pull-out bars

Figure 4.5.1 – Tested specimens

Description of failure mode: Explosive followed by small fibres all around.



Stress vs displacement



Stress vs Strain

Figure 4.5.2

4.6. Specimens *C-2.5x15-S*

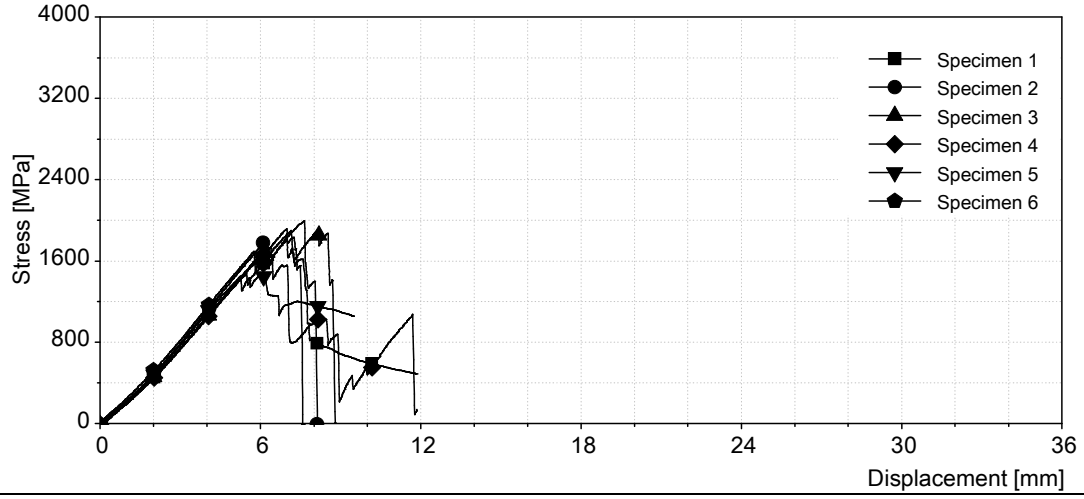
Table 4.6.1 – Tensile proprieties of C-2.5x15-S specimens

Name	D [mm]	F_u [kN]	f_u [MPa]	ε_u [%]	$E_{(0.1\text{-}0.3\ ‰)}$ [GPa]	$E_{(ISO)}$ [GPa]	Failure aspect
C-2.5x15-S-1	2.5x15	71.39	1903.66	1.10	173.83	171.46	LS
C-2.5x15-S-2	2.5x15	74.95	1998.73	1.18	167.14	172.08	LS
C-2.5x15-S-3	2.5x15	71.87	1916.43	1.11	171.11	173.33	LS
C-2.5x15-S-4	2.5x15	62.45	1665.46	0.97	170.72	171.00	LS
C-2.5x15-S-5	2.5x15	55.30	1474.79	0.88	168.00	168.36	LS
C-2.5x15-S-6	2.5x15	72.05	1921.22	1.12	170.59	171.94	LS
Mean	-	68.00	1813.38	1.06	170.23	171.36	-
St. deviation	-	7.52	200.64	0.11	2.40	1.67	-

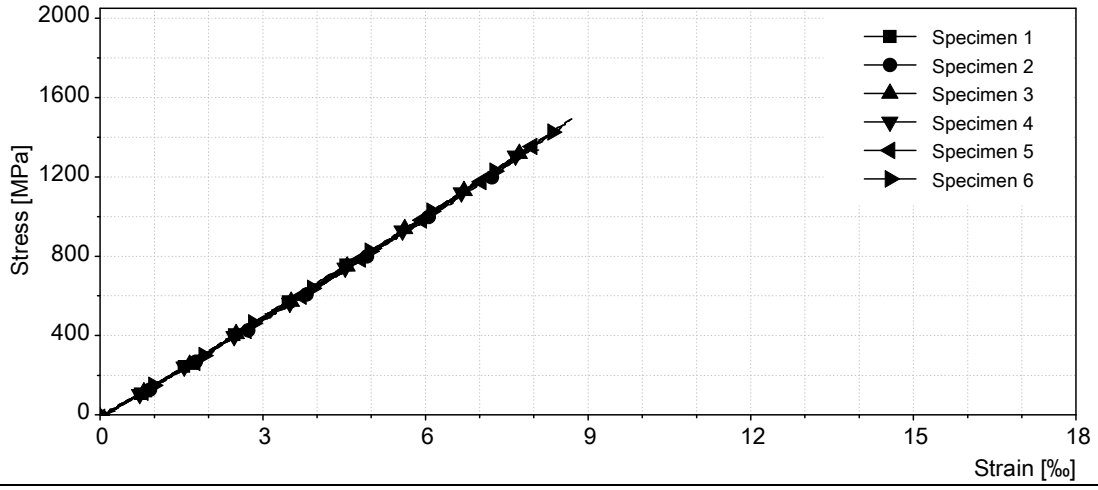
Failure aspects:
LS: longitudinal splitting and fibre fracture
PO: Pull-out bars

Figure 4.6.1 – Tested specimens

Description of failure mode: Not much explosive, and not too messy. However, the type of failure occurred did not correspond exactly to the one expected. The fibres split longitudinally but fractured too close to the end tabs.



Stress vs displacement



Stress vs Strain

Figure 4.6.2

4.7. Specimens *C-8-S*

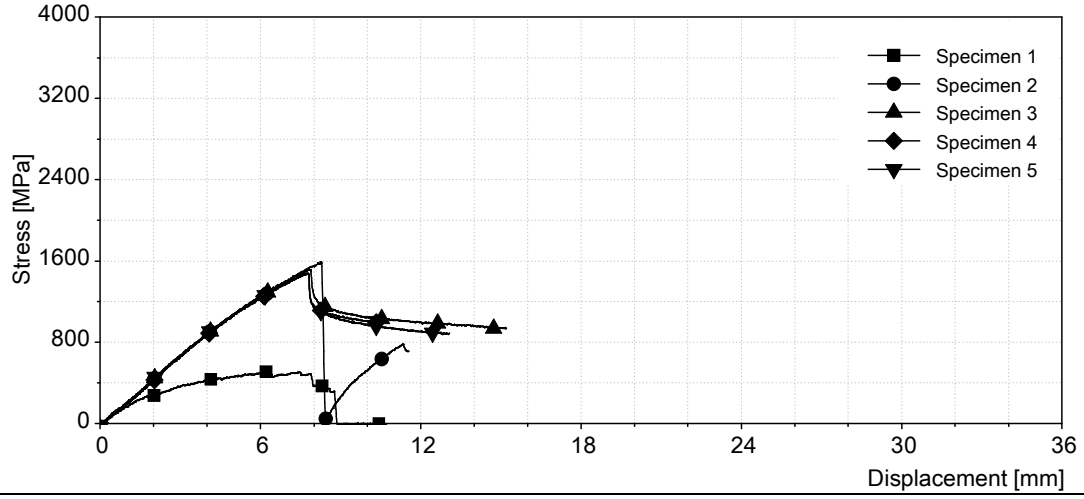
Table 4.7.1 – Tensile proprieties of C-8-S specimens

Name	D [mm]	F_u [kN]	f_u [MPa]	ε_u [%]	$E_{(0.1\text{-}0.3\ ‰)}$ [GPa]	$E_{(ISO)}$ [GPa]	Failure aspect
C-8-S-1	8.00	33.68	670.00	-	-	-	LS
C-8-S-2	8.00	88.10	1752.73	1.23	140.40	144.58	PO
C-8-S-3	8.00	84.38	1678.70	1.06	155.46	160.42	PO
C-8-S-4	8.00	82.33	1637.98	1.02	159.75	162.62	PO
C-8-S-5	8.00	82.33	1637.98	1.06	150.55	158.51	PO
Mean	-	74.17	1475.48	1.09	151.54	156.53	-
St. deviation	-	22.76	452.71	0.09	8.32	8.14	-

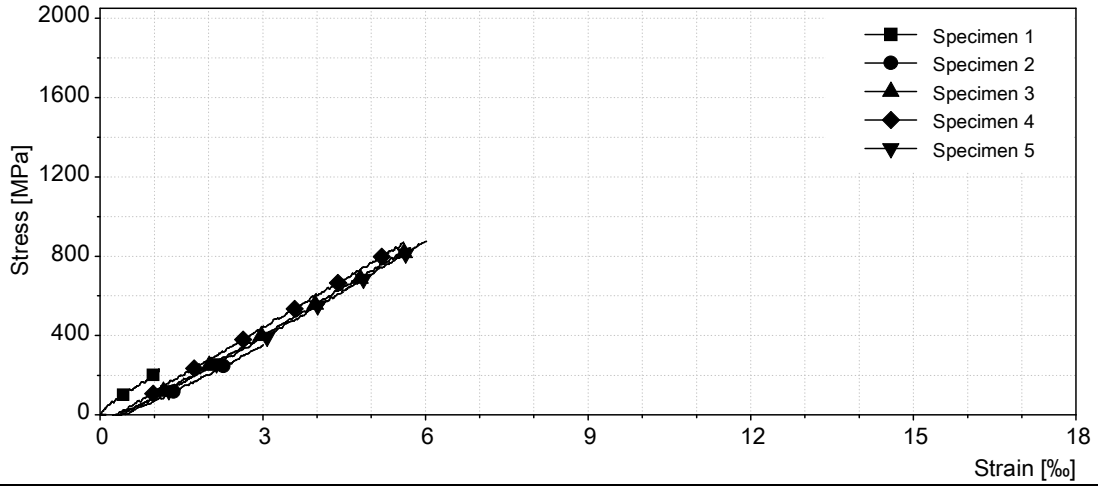
Failure aspects:
LS: longitudinal splitting and fibre fracture
PO: Pull-out bars

Figure 4.7.1 – Tested specimens

Description of failure mode: The first specimen only failed because it was accidentally pre-compressed. In all other cases, the anchorage length was insufficient. In most of the specimens the bar was debonded from the adhesive.



Stress vs displacement



Stress vs Strain

Figure 4.7.2

4.8. Specimens *C-10x10-S*

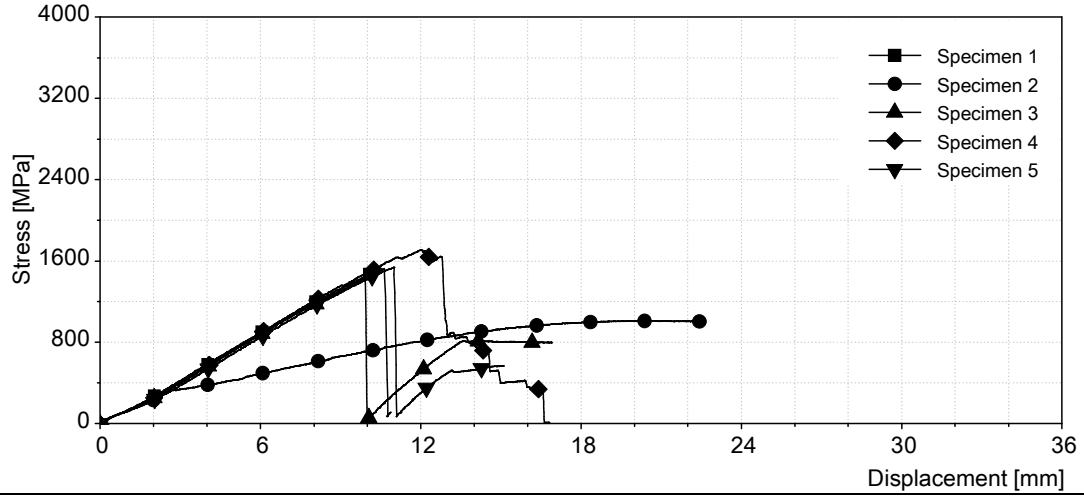
Table 4.8.1 – Tensile proprieties of C-10X10-S specimens

Name	D [mm]	F_u [kN]	f_u [MPa]	ε_u [%]	$E_{(0.1\text{-}0.3\ ‰)}$ [GPa]	$E_{(ISO)}$ [GPa]	Failure aspect
C-10x10-S-1	10x10	158.90	1589.00	0.91	172.54	176.27	PO
C-10x10-S-2	10x10	107.82	1078.25	0.61	175.19	175.69	PO
C-10x10-S-3	10x10	148.48	1484.80	0.84	176.10	179.54	PO
C-10x10-S-4	10x10	177.41	1774.13	0.97	182.74	183.27	LS
C-10x10-S-5	10x10	160.11	1601.09	0.89	179.45	181.52	PO
Mean	-	150.55	1505.45	0.84	177.20	179.26	-
St. deviation	-	26.04	260.41	0.14	3.96	3.28	-

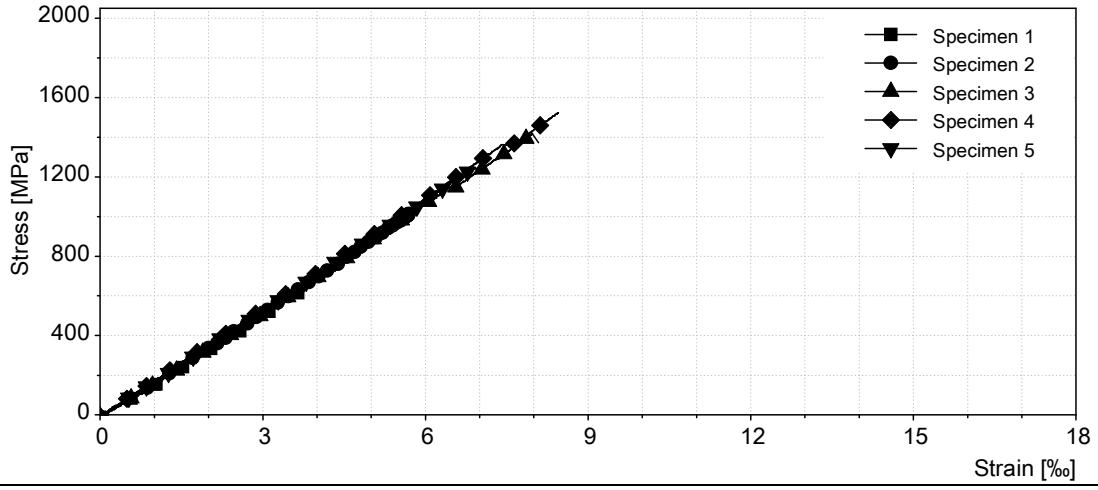
Failure aspects:
LS: longitudinal splitting and fibre fracture
PO: Pull-out bars

Figure 4.8.1 – Tested specimens

Description of failure mode: Only one specimen has ruptured. In spite of using an anchorage length of 250 mm in these specimens (the maximum in all test program), the other four did not fail. It seems that with a little higher anchorage length the rupture of these bars can be attained.



Stress vs displacement



Stress vs Strain

Figure 4.8.2

5. Acknowledgements

The study reported in this paper forms a part of the research program “CUTINEMO” supported by FCT, PTDC/ECM/73099/2006. The authors wish to acknowledge the support also provided by the Casais, S&P, SECIL and Artecanter Companies. The second Author acknowledges the grant under the aforementioned research project (SFRH/BD/61756/2009).