COST Action TU1207

Next Generation Design Guidelines for Composites in Construction

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Mechanical characterization of the filament wound pipes for construction

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Application in construction

rebar, beams, decks, safety barriers, rebar for concrete bridge decks, parapets, retaining structures, to reinforce concrete columns etc.

filament wound glass reinforced plastic pipes

Corrosion Resistant
Lightweight
Ease of Installation
Custom Fabrication

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Properties of fiber reinforced composites (FRP)

- its constituent materials,
- their distribution,
- their volume ratio,
- the orientation of the fibres in the matrix,
- the properties of the fibre-matrix bond,
- the interaction among them,
- the adhesion.

an unusual combination of material properties can be obtained!

Mechanical properties of FRP

- the mechanical compatibility between the fibres and the matrix
- the angle between the fibres and the direction of loading.

The tensile behaviour:

- by the reinforcing fibres
- the failure strain of the matrix should be greater than that of the fibres (to prevent the development of microcracks in the matrix before reaching the fibre's elongation limit)

The compression behaviour:

- a minimum stiffness of the matrix is required to prevent buckling of the fibres.

Test Specimen Fabrication

Filament winding technique - widely used technique for filament wound pipe production

The different models of filament wound pipes were produced.

Epoxy matrix system from Huntsman:
Araldite LY1135-1 is an epoxy resin
Aradur 917 is an anhydride hardener
Accelerator 960 is an amine accelerator

E-glass, continuous filament from Owens Corning – **P185 1200 tex**

Laboratory at Institute for Advanced Composites and Robotics

Full factorial experimental design - 2^3

No. exp.	Matrix of full factorial experimental design							Characteristics (conditions of the experiment)		
	X_1	X_2	X_3	$X_1 X_2$	$X_1 X_3$	$X_2 X_3$	$X_1 X_2 X_3$	**X_1 (m/min)** *velocity of the filament winding*	**X_2 (N)** *fibre tension*	**X_3 (^{0})** *winding angle*
1	-1	-1	-1	+1	+1	+1	-1	5,25	64	10
2	+1	-1	-1	-1	-1	+1	+1	21	64	10
3	-1	+1	-1	-1	+1	-1	+1	5,25	110	10
4	+1	+1	-1	+1	-1	-1	-1	21	110	10
5	-1	-1	+1	+1	-1	-1	+1	5,25	64	90
6	+1	-1	+1	-1	+1	-1	-1	21	64	90
7	-1	+1	+1	-1	-1	+1	-1	5,25	110	90
8	+1	+1	+1	+1	+1	+1	+1	21	110	90

Primary level	X_1 = 13,125	X_2 = 87	X_3 = 50
Interval of variation	7,875	23	40
Lower level	5,25	64	10
Upper level	21	110	90

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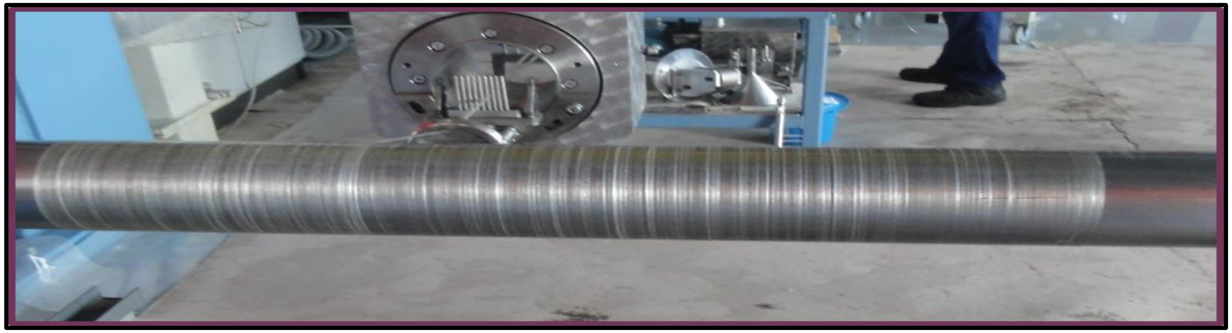
Samples with different winding designs



winding angle = 90^0

winding angle = 45^0

winding angle = 10^0

very low winding angle - need some arrangements at the ends of the mandrel, such as pins, etc

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Test Specimens

- two-step curing program:
  curing at 80°C, for four hours
  curing at 140°C, for four hours
- removal of the mandrel from the specimens
- each specimen was then cut so as to obtain test specimens

Mechanical characterization of the filament wound pipes

The tensile strength testing – Hoop Tensile Test

- ASTM D2290: Standard Test Method for Apparent Hoop Tensile Strength of Plastic Or Reinforces Plastic Pipe by Split Disk Method

The compressive strength testing – Transverse Compressive Test

- ASTM D5449: Standard Test Method for Transverse Compressive Properties of Hoop Wound Polymer Matrix Composite Cylinders

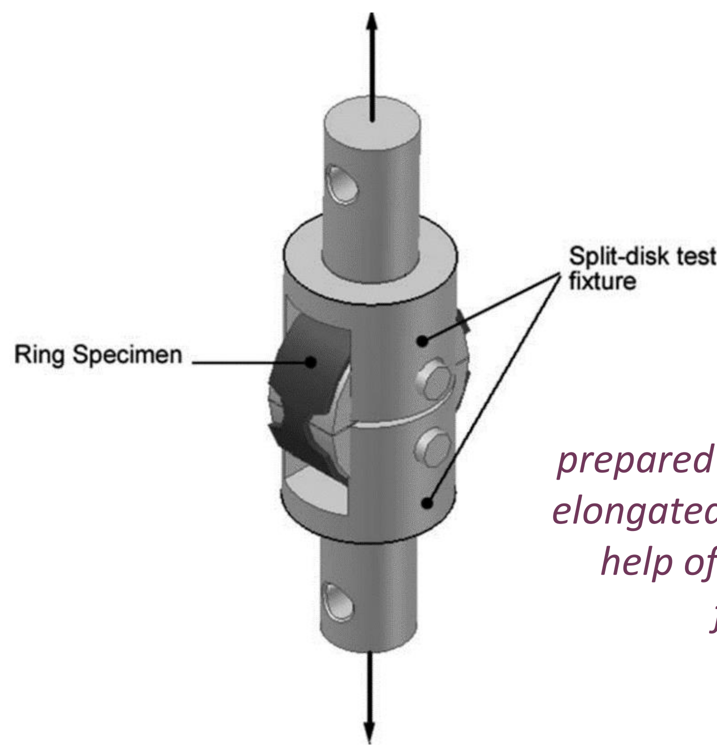
The tensile strength testing

- at room temperature
- universal testing machines:

Zwick / Roell Z050 with max. load of 50 kN

Zwick / Roell Z400 with the max. stress of 400 Mpa

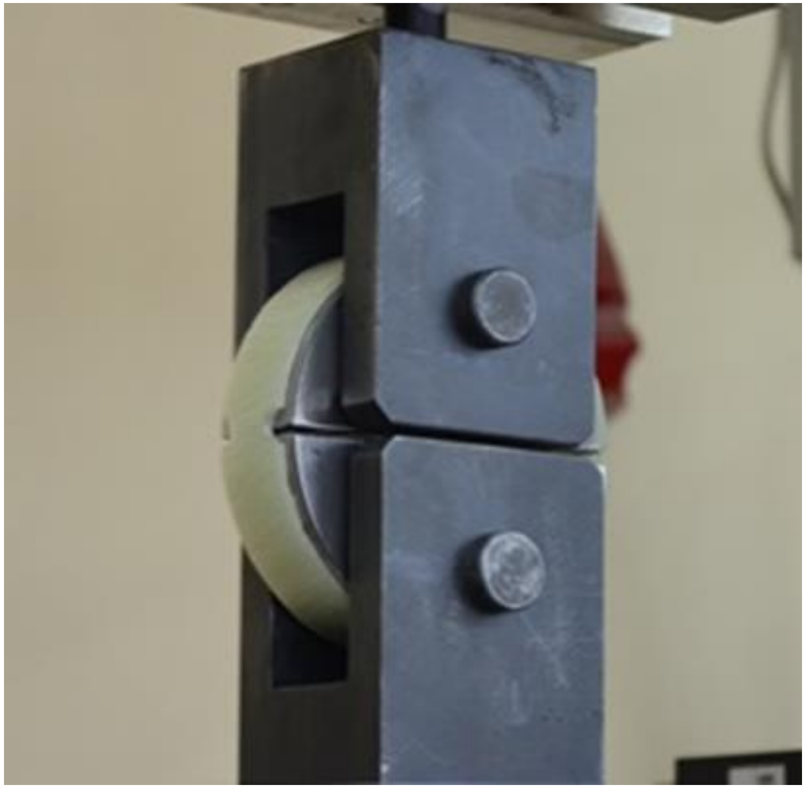
- loading speed of 0.3 inch/min



prepared specimens were elongated till rupture with help of split-disk test fixtures

Illustration of the assembled tensile test fixture and specimens

split-disk test specimen



test fixture with specimen for tensile testing

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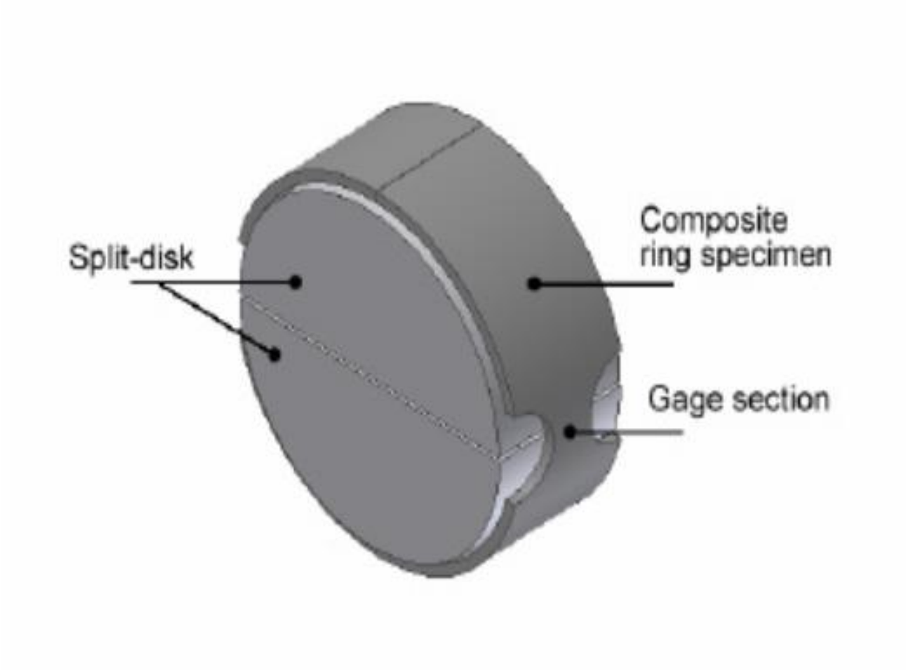
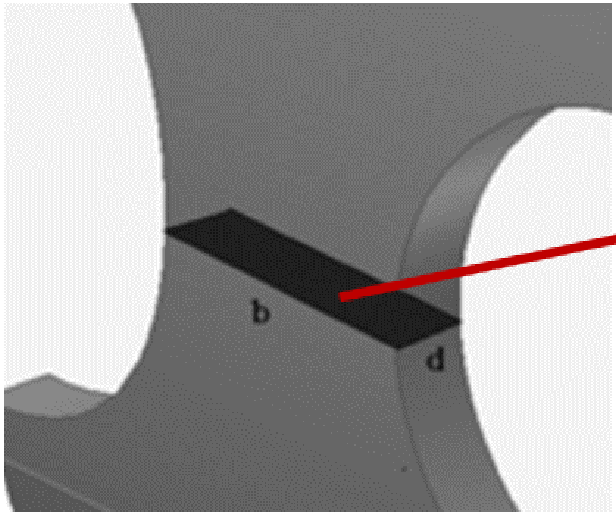
Cross-sectional area on which hoop tensile stress is applied





minimum cross-sectional area
b ≈ 14mm,
d ≈ 3mm

$$\sigma = \frac{F_{\max}}{2 \cdot A_m}$$

Fmax - maximum load prior to failure recorded in Newton (N)

Am - minimum cross-sectional area of the two reduced sections, d x b, mm^2

σ - hoop tensile strength, MPa,

Hoop tensile strength results of split-disk tests

Sample Designation		b (mm)	d (mm)	A (mm)^2	F (kN)	F average (kN)	σ (MPa)	σ average (MPa)
1	1-1	14,07	3,20	45,01	80,6	70,7	895,36	788,09
	1-2	14,01	3,19	44,76	68,5		765,19	
	1-3	13,99	3,20	44,77	65,7		733,75	
	1-4	14,14	3,20	45,28	61,5		679,11	
	1-5	14,05	3,17	44,52	77,20		867,03	
2	2-1	14,14	3,14	44,40	73,50	70,7	827,70	796,22
	2-2	14,14	3,12	44,12	64,70		733,23	
	2-3	14,17	3,15	44,64	73,90		827,73	
3	3-1	14,00	3,08	43,19	77,60	74,14	898,36	853,58
	3-2	14,07	3,09	43,49	74,10		851,92	
	3-3	14,08	3,09	43,51	74,60		857,27	
	3-4	14,08	3,09	43,51	71,40		820,50	
	3-5	14,02	3,10	43,46	73,00		839,85	
4	4-4	14,15	3,65	51,65	72,30	74,95	699,90	725,84
	4-5	14,14	3,65	51,61	77,60		751,79	
5	5-1	14,12	3,27	46,17	2,29	2,17	24,8	23,57
	5-2	14,2	3,27	46,43	2,40		25,84	
	5-3	14,19	3,27	46,40	2,25		24,25	
	5-4	14,17	3,20	45,34	1,97		21,72	
	5-5	14,17	3,24	45,91	1,95		21,24	
6	6-1	14,12	3,15	44,48	1,96	1,89	22,03	20,99
	6-2	14,08	3,20	45,06	2,03		22,52	
	6-3	14,09	3,20	45,09	1,92		21,29	
	6-4	14,16	3,20	45,31	1,82		20,08	
	6-5	14,04	3,20	44,93	1,71		19,03	
7	7-1	14,08	3,17	44,70	1,48	1,47	16,55	16,51
	7-2	14,10	3,15	44,42	1,55		17,45	
	7-3	14,07	3,17	44,60	1,13		12,67	
	7-4	14,00	3,17	44,38	1,72		19,38	
8	8-1	14,00	2,95	41,30	1,39	1,41	16,83	16,95
	8-2	14,00	2,95	41,30	1,43		17,07	
9	9-1	14,05	3,18	44,68	25,14	24,69	281,33	284,90
	9-2	14,01	3,00	42,03	24,25		288,48	

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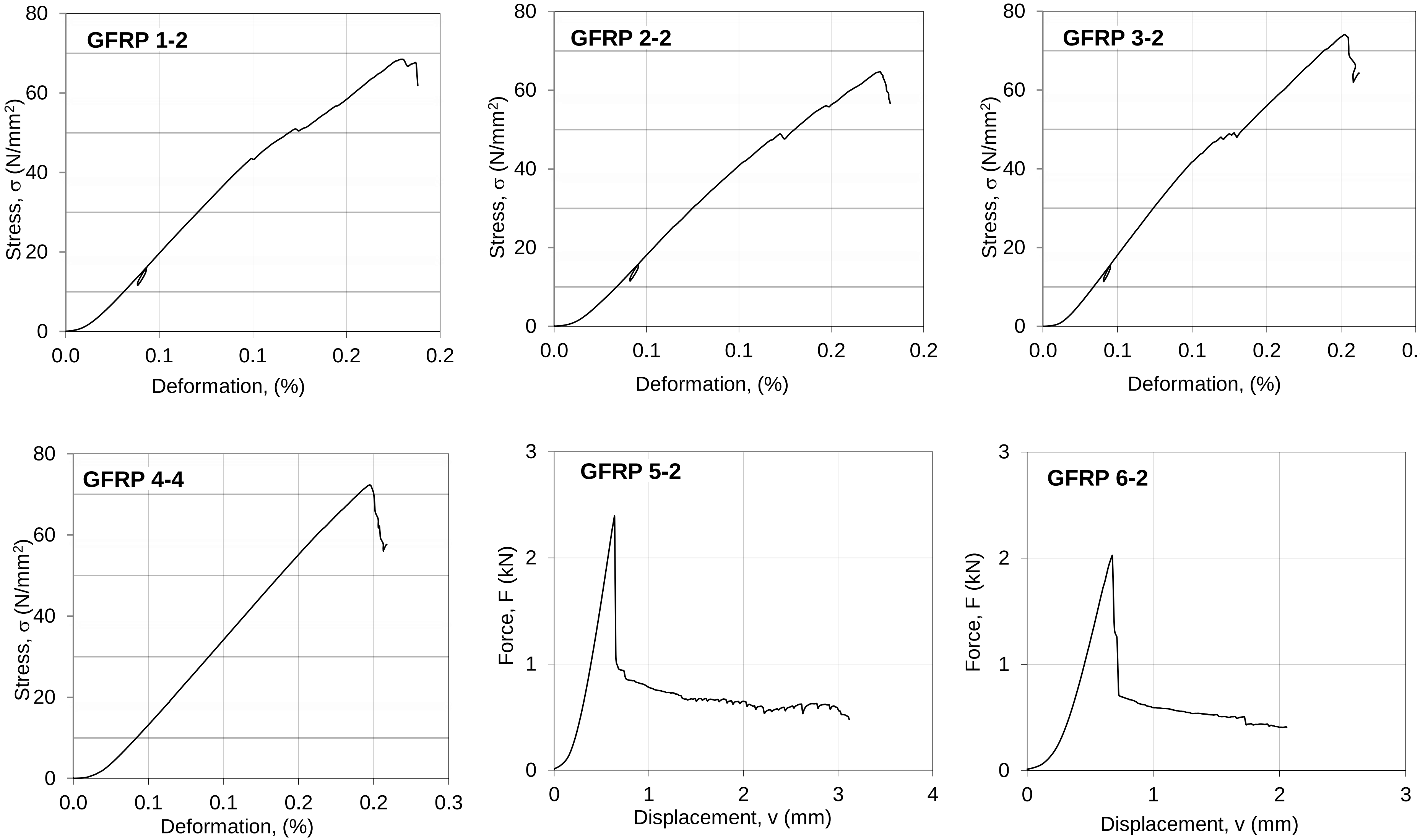
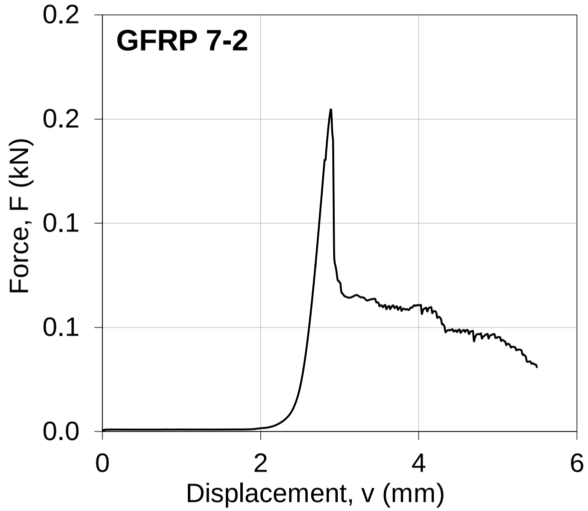
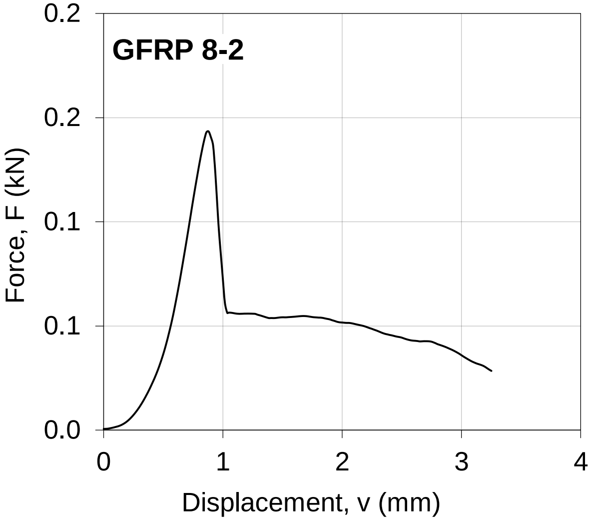
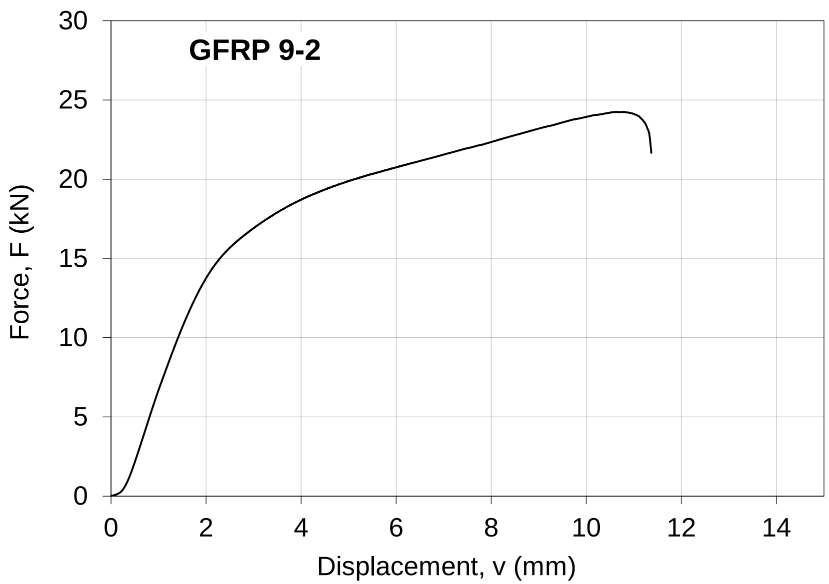
Force and displacement graphs of split disk samples



Force and displacement graphs of split disk samples







Damages made during tensile tests

*split-disk specimen with **10^0** winding angle of the glass fibers*

*split-disk specimen with **90^0** winding angle of the glass fibers*

*split-disk specimen with **45^0** winding angle of the glass fibers*

significantly lower tensile strength

best results

The tensile strength testing - data analysis and conclusions

- The **best results** were obtained for a series of **samples 1 to 4**, characterized by the filament **winding angle of 90^0**.

- **Samples 5 to 8**, winded with very low angle **10^0** relative to the longitudinal axis of the mandrel have a significantly lower tensile strength.

- The split-disk **specimens 9 series**, with angle **45^0**, had shown ten times better tensile strength from samples 5 – 8 but less than samples 1 – 4.

- The fiber tension and velocity of the filament winding don't influence the tensile strength of the specimens.

The tensile properties of composite specimens depended from winding angles in filament winding technology.

The bigger winding angle lead to higher hoop tensile properties of filament-wound tubular samples.

The compressive strength testing

pipe test specimen

test fixture with specimen

- at room temperature
- universal testing machines: *Zwick / Roell Z400 with the max. stress of 400 Mpa*
- loading speed of 0.05 in/min

Filament wound cylinders with 100 mm in diameter and 140 mm in length bonded into two end fixtures were tested.

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The transverse compressive strength was determined from the maximum load carried before failure:

$$\sigma = \frac{F_{\max}}{A}$$

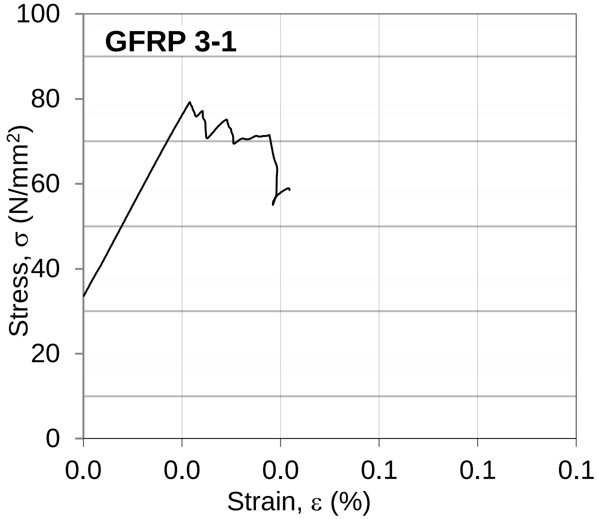
$$A = \frac{\pi}{4}\left(OD^2 - ID^2\right)$$

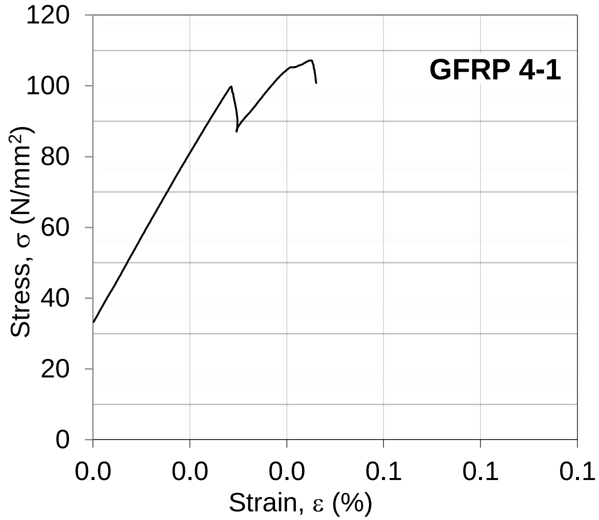
A is the cross-sectional area,
ID is the average inner diameter,
OD is the average outer diameter.

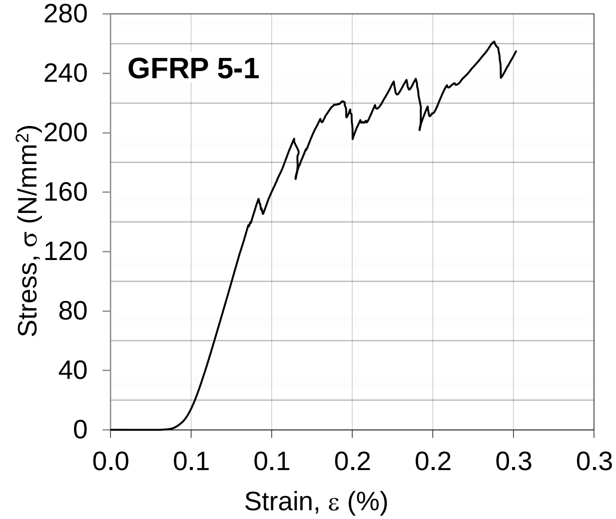
Transverse compressive strength results of pipe specimens

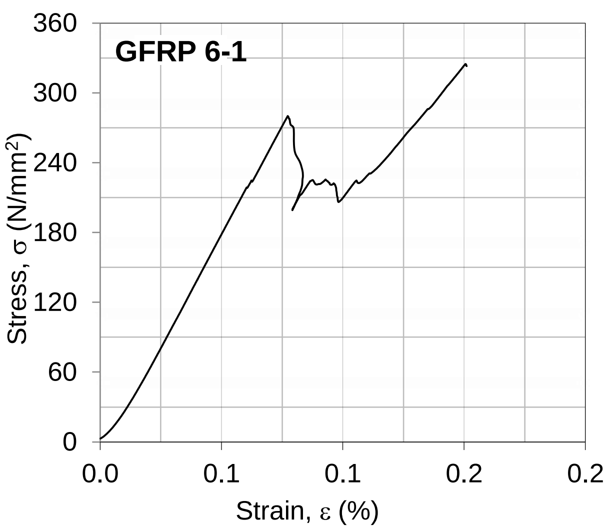
Sample Designation		l (mm)	OD (mm)	ID (mm)	A $(mm)^2$	F_{max} (kN)	F average (kN)	σ (MPa)	σ average (MPa)
1	1-1	140,00	106,20	99,90	10,20	913,92	1029,21	89,60	**102,67**
	1-2	140,00	106,20	100,00	10,03	1127,97		112,46	
	1-3	139,80	106,10	100,00	9,87	1045,73		105,95	
3	3-1	140,00	106,20	100,00	10,03	792,37	856,60	79,00	**83,86**
	3-2	140,00	106,30	99,90	10,37	817,78		78,86	
	3-3	140,10	106,20	100,00	10,30	959,65		93,71	
4	4-1	140,00	106,85	100,10	10,95	1070,58	1019,99	97,77	**93,58**
	4-2	140,10	106,60	100,00	10,70	962,36		89,94	
	4-3	140,00	106,90	100,10	11,04	1027,05		93,03	
5	5-1	139,90	106,65	99,60	11,46	2558,90	3156,61	223,29	**274,54**
	5-2	140,00	106,60	99,50	11,54	3518,43		304,89	
	5-3	140,10	106,70	99,50	11,71	3392,50		289,71	
6	6-1	140,00	106,20	99,50	10,87	3263,93	3025,21	300,27	**271,49**
	6-2	140,00	106,60	99,60	11,37	3514,24		309,08	
	6-3	139,90	106,40	99,50	11,20	2297,46		205,13	
7	7-1	140,05	106,20	100,00	10,03	2358,45	2241,28	235,14	**216,59**
	7-2	139,90	106,50	99,90	10,70	2582,23		241,33	
	7-3	140,00	106,35	100,00	10,29	1783,15		173,29	
9	9-1	140,10	106,60	99,50	11,54	1512,78	1539,93	131,09	**131,82**
	9-2	139,90	106,80	99,45	11,96	1600,01		133,78	
	9-3	140,10	106,60	99,50	11,54	1507,01		130,59	

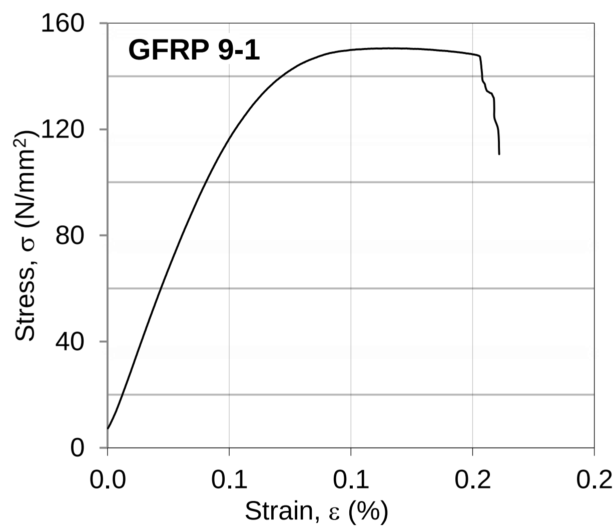
Stress and strain curves of pipe samples from transverse compressive testing











Damages made during compression tests of the pipe specimens with different winding angle of the glass fibers

pipe specimen with
***10⁰** winding angle*
of the glass fibers

best results

pipe specimen with
***90⁰** winding angle*
of the glass fibers

lower value

pipe specimen with
***45⁰** winding angle*
of the glass fibers

The compression strength testing - data analysis and conclusions

- The **best results** were obtained for a series of **samples 5 to 8**, characterized by the filament **winding angle of 10^0**.
- **Pipe specimens 1 to 4**, winded with very low angle **90^0** had shown much lower value almost for 50%.
- The split-disk **specimens 9 series**, with angle **45^0**, had shown better tensile strength from samples 1 – 4 but less than samples 5 – 8.
- ***The lower winding angle lead to higher transverse compression properties of filament-wound tubular samples.***
- Slight influence of the fiber tension on the compression strength: **the higher fiber tension leads to higher value of the compression strength**.
- The velocity of the filament winding don't influence the compressive strength of the specimens.

- *Significant differences in the filament wound pipes with different fiber orientation.*
- *Slight influence of the fiber tension and velocity of the filament wound pipes*
- *The optimal mechanical properties have the samples on the primary level winded with angle 45^0*

Thank you

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