

Tensile properties of structural fibre reinforced concrete

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Abstract. The paper deals with the comparison of several loading tests, which are using for determination of tensile strength of cementitious composites. The paper describes several test methods, their advantages, disadvantages and possible outputs. In the experimental program several recipes of concrete and fibre reinforced concrete were tested in splitting test, 3-point and 4-point bending tests and in 2 variants of axial tension test. Tension strength ratios and conversion factors between loading tests were determined for each recipe, based on test results.

1. Introduction

Tensile strength is one of the fundamental material parameters, which is ordinarily used for structure design. It is usually determined experimentally based on destructive tests. There are several methods for testing the tensile strength of cementitious composites and their behaviour in tension. The test methods vary in their technical difficulty, accuracy and variance of results. Although all tests provide information on the strength in a particular strain, these strength values are different in different tests. A possibility of the results comparison is very important for the structural design in practice.

2. Test methods for determining the tensile strength

2.1. Splitting test

Splitting test is technically less difficult test for determining the tensile strength of cementitious composite. It can be realized on cube-shaped or cylindrical specimens (figure 1). The specimen is loaded by compressive force in constant loading rate (increase of tensile splitting strength) 0.04 - 0.06 MPa/s [1]. This test provides the value of maximal material tensile splitting strength and residual tensile splitting strength depending on the transverse strain in case there are extensometers on the specimen surface (figure 2).

2.2. Bending test

Bending test is the most commonly used test for determining and verifying the tensile properties of fibre reinforced concrete and its behaviour after macrocracking. Here are a lot of arrangements of concrete and fibre reinforced concrete bending tests. These cases vary in the shape and dimensions of specimen, in supporting and load arrangement. Two modifications of bending test are standardized: 3-point bending test and 4-point bending test.



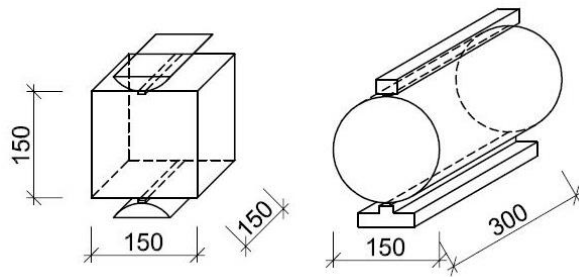


Figure 1. Shape of specimens for splitting test of concrete and fibre reinforced concrete.

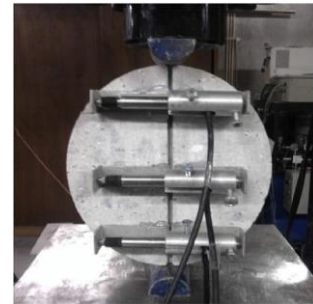


Figure 2. Extensometers on the specimen surface in splitting test [2]

2.2.1. 3-point bending test. Beam specimen with standardly cross-section 150×150 mm is simply supported by span 500 mm and force loaded in the middle of span (figure 3). Un-notched or notched beams with the notch in the middle of span can be used. The width of potential notch is 5 mm a depth 25 mm [3]. This notch defines the cross-section, where the macrocrack is formed. The loading rate can be phased or it is constant throughout the test - increase of middle deflection 0.2 mm/min. Dependence load - central deflection ($F_R - \delta$) is recorded during the test. In the case of notched beam it is possible to install the extensometer near the notch for notch opening displacement measuring [9]. The output is than dependence load - crack mouth opening displacement ($F_R - CMOD$). Disadvantages of this arrangement are direct definition of failure cross-section, where isn't generally the worst material properties and complicated stress near the notch. The results are higher values of measured strengths.

2.2.2. 4-point bending test. Only un-notched beams are used for 4-point bending test. The standard cross-section is 150×150 mm a length 700 mm [4]. Beams are simply supported by span 600 mm and loaded with pair of forces in thirds of span (figure 4). The loading rate can again be phased into 3 laps or it is constant throughout the test - increase of middle deflection 0.2 mm/min [8]. Dependence load - central deflection ($F_R - \delta$) is recorded during the test. Advantage of this arrangement is the fact that failure occurs in the middle third of span, where shear force isn't and critical cross-section is loaded only with bending moment. Disadvantage is the fact that the failure point is unknown and it isn't possible to install the extensometers for crack mouth opening displacement measurement.

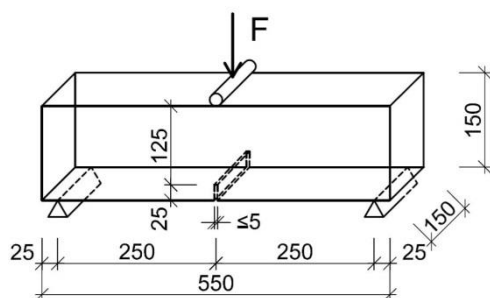


Figure 3. 3-point bending test

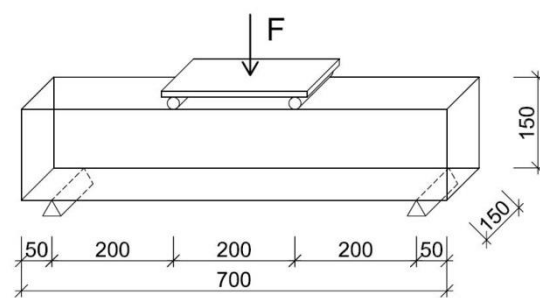


Figure 4. 4-point bending test

2.3. Axial tension test

Axial tension test isn't commonly used, because it is very technically difficult. At present there are few rules and recommendations that clearly define the test arrangement of fibre reinforced concrete in axial tension.

Recommendation RILEM [5] prescribe a notched cylindrical specimen with diameter of 150 mm and min. height of 150 mm. The notch should be performed over the whole periphery with a constant depth of 15 mm and a constant width max. 5.0 mm (figure 5). The specimen is fixed via glue joint on the ends of cylinder. In the notch there are installed three LVDT sensor, which measure notch mouth opening displacement and also control loading. Loading is divided to 2 phases with loading rate of 0.005 mm/min and 0.1 mm/min. Dependence F_R - $CMOD$ is recorded. Disadvantages of this arrangement are permanent connection of specimen, which complicates quick test repeatability and again direct definition of critical cross-section. It is also suitable only for material with softening behaviour, because only one macrocrack can form.

They are also known other arrangements of axial tension test, which eliminate these disadvantages. One of them has been developed at Department of Concrete and Masonry Structures, Faculty of Civil Engineering, CTU in Prague. It use dogbone specimen with rectangular cross-section and its two-level reduction (figure 6). Longitudinal deformations of central part of specimens are measured with two sensors, which are situated on the opposite surfaces of specimen. The specimen is mechanically clamped, it allow easy test repeatability.

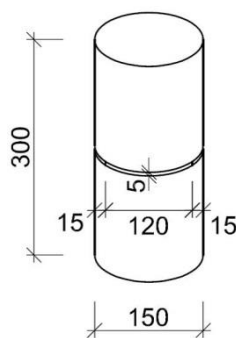


Figure 5. Axial tension test - notched cylinder

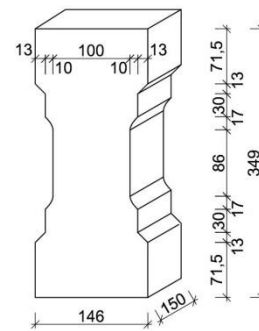


Figure 6. Axial tension test - dogbone

3. Experimental comparison of loading tests

The aim of experiments was to compare the values of tensile strength of various composites, which were determined in different loading test and quantify the conversion factors between loading tests for each tested recipe.

Six recipes of concrete and fibre reinforced concrete were tested in splitting test, 3-point and 4-point bending tests and two variants of axial tension test. All recipes had the same concrete matrix and various type and dose of fibres. Portland cement CEM I 42.5 R, granite aggregate in fractions 0/4 - 4/8 - 8/16 and superplasticizer Sika Visco Crete - 1035 CZ were used. The fibres were TriTreg 50/1,05mm, Dramix RC 80/60 BN, Fibrex A1 and Dramix 5D 65/60 BG in dose of 0 to 3.0 % by volume. Cubed specimens with edge 150 mm were used for splitting tests, the other test were arranged as shown in chapter 2 (figures 3 to 6). Only maximal loading force was recorded in splitting test. Dependence load force - central deflection (F_R - δ) was recorded in bending tests and dependence load force - deformation of monitored area (F_R - Δ_t) was recorded in axial tension tests.

A detailed description of the recipes and realized tests is given in [6].

3.1. General experiment results

The tests have showed clearly positive effect of fibres for specimen resistance both at and after macrocracking. The values of tensile strength and strain at macrocracking increase with increasing dose of fibres. Ductility of material increase also with dose of fibres, but type and length of fibres have significant influence.

Brittle failure at macrocracking is typical for ordinary concrete in all tests variants, there isn't possible to record the residual part of stress-strain diagram. The material with lower quality fibres or with lower dose of fibres has exhibited the softening behaviour after macrocracking in bending tests, but there was brittle failure in axial tension test. The materials with higher dose of fibres have exhibited hardening behaviour in bending test and softening behaviour in axial tension tests.

3.2. Comparison of test results, material properties

The values and ratios of tensile strengths at macrocracking for tested material are shown in table 1, the values and ratios of stain at macrocracking are shown in table 2. The values and ratios of residual tensile strengths are shown in table 3.

Table 1. Mean values of tensile strength at the macrocracking $f_{t,cr}$ [MPa].

Recipe	splitting test cube 150×150×150mm		3-point bending notched beam 150×150×600mm		4-point bending un-notched beam 150×150×700mm		axial tension notched cylinder 150×300mm		axial tension dogbone 146×150×349mm
	$f_{t,sp}$ [MPa]	$f_{t,sp}$ / $f_{t,ax}$	$f_{t,3P}$ [MPa]	$f_{t,3P}$ / $f_{t,ax}$	$f_{t,4P}$ [MPa]	$f_{t,4P}$ / $f_{t,ax}$	$f_{t,ax,cyl}$ [MPa]	$f_{t,ax,cyl}$ / $f_{t,ax}$	$f_{t,ax}$ [MPa]
1 reference concrete	3.60	1.32	4.87	1.79	4.84	1.78	3.37	1.24	2.72
2 0.5% TT	4.45	1.29	5.18	1.51	4.82	1.40	3.83	1.11	3.44
3 1.0% TT	4.70	1.33	5.93	1.68	5.55	1.57	4.06	1.15	3.53
4 1.0% Dr 80/60	6.20	1.53	-	-	6.30	1.55	-	-	4.06
5 3.0% TT+Fib	8.80	1.78	-	-	6.48	1.44	-	-	4.50
6 0.64% Dr 65/60	-	-	-	-	5.17	1.58	-	-	3.28
Standard:		1.18		1.67		1.45		1.00	

Table 2. Mean values of tensile strain at the macrocracking $\varepsilon_{t,cr}$ [‰].

Recipe	3-point bending notched beam 150×150×600mm		4-point bending un-notched beam 150×150×700mm		axial tension notched cylinder 150×300mm		axial tension dogbone 146×150×349mm
	$\varepsilon_{t,3P}$ [‰]	$\varepsilon_{t,3P}$ / $\varepsilon_{t,ax}$	$\varepsilon_{t,4P}$ [‰]	$\varepsilon_{t,4P}$ / $\varepsilon_{t,ax}$	$\varepsilon_{t,ax,cyl}$ [‰]	$\varepsilon_{t,ax,cyl}$ / $\varepsilon_{t,ax}$	$\varepsilon_{t,ax}$ [‰]
1 reference concrete	0.30	1.43	0.22	1.05	0.18	0.86	0.21
2 0.5% TT	0.34	1.89	0.29	1.61	0.21	1.17	0.18
3 1.0% TT	0.45	1.73	0.33	1.27	0.22	0.85	0.26
4 1.0% Dr 80/60	-	-	0.33	1.14	-	-	0.29
5 3.0% TT+Fib	-	-	0.27	0.69	-	-	0.39
6 0.64% Dr 65/60	-	-	0.22	1.38	-	-	0.16

The strength ratios between splitting test $f_{t,cr,sp}$ and axial tension test $f_{t,ax}$ are in the range, which is higher than the values in document [7]. It is also evident, that the ratio increases with the strength of material and with the dose of fibres.

The 3-point bending test shows higher values of tensile strength at macrocracking than 4-point bending test in all recipes. The strength ratios between bending tests ($f_{t,cr,3P}$ and $f_{t,cr,4P}$) and axial tension test $f_{t,cr,ax}$ are in ranges of values specified in documents [3] and [4], wherein the clear dose-dependency of the used fibres has not been demonstrated.

The axial tension test with notched cylindrical specimens shows higher values by 11 to 24 percent of strength at macrocracking than the test with dogbone specimens. This is because the notch defines the failure point, which may not be the place with the worst material properties.

The values of material tension strain at macrocracking $\varepsilon_{t,cr}$ are strongly dependent on the type of used test. The difference in strain $\varepsilon_{t,cr}$ between 4-point bending and axial tension is relatively small, while 3-point bending shows significant increase of this value.

Table 3. Mean values of residual tensile strength $f_{t,res}$ [MPa].

$\varepsilon_{t,res}$	Recipe	3-point bending			4-point bending		axial tension		axial tension
		notched beam 150×150×600mm			un-notched beam 150×150×700mm		notched cylinder 150×300mm		dogbone 146×150×349mm
		$f_{t,3P}$ [MPa]	$f_{t,3P} / f_{t,ax}$	$f_{t,3P} / f_{t,4P}$	$f_{t,4P}$ [MPa]	$f_{t,4P} / f_{t,ax}$	$f_{t,ax,cyl}$ [MPa]	$f_{t,ax,cyl} / f_{t,ax}$	$f_{t,ax}$ [MPa]
2.0 ‰	2 0.5% TT	1.62	-	1.11	1.46	-	0	-	0
	3 1.0% TT	2.86	2.42	1.26	2.27	1.92	1.20	1.02	1.18
	4 1.0% Dr 80/60	-	-	-	3.28	2.34	-	-	1.40
	5 3.0% TT+Fib	-	-	-	3.43	1.54	-	-	2.23
5.0 ‰	2 0.5% TT	1.44	-	1.12	1.29	-	0	-	0
	3 1.0% TT	2.64	2.34	1.10	2.41	2.13	1.18	1.04	1.13
	4 1.0% Dr 80/60	-	-	-	3.67	2.22	-	-	1.65
	5 3.0% TT+Fib	-	-	-	3.17	1.46	-	-	2.17
10.0 ‰	2 0.5% TT	1.31	-	1.17	1.12	-	0	-	0
	3 1.0% TT	2.39	2.28	1.06	2.26	2.15	1.13	1.08	1.05
	4 1.0% Dr 80/60	-	-	-	3.50	2.35	-	-	1.49
	5 3.0% TT+Fib	-	-	-	2.69	1.43	-	-	1.88
20.0 ‰	2 0.5% TT	1.11	-	1.13	0.98	-	0	-	0
	3 1.0% TT	1.98	2.08	1.08	1.83	1.93	1.02	1.07	0.95
	4 1.0% Dr 80/60	-	-	-	2.98	2.29	-	-	1.30
	5 3.0% TT+Fib	-	-	-	1.84	1.67	-	-	1.10
Standard:			1.67			1.45		1.00	

Higher tensile strength in 3-point bending test than in 4-point bending test is also evident after macrocracking (figure 7). Comparison of test results in bending tests and axial tension test is limited to recipe 3 in case 3-point bending test (figure 7) and to recipes 3, 4 and 5 in case 4-point bending test

(figure 8). Here was a brittle failure at the material with lower dose of fibres in axial tension test, so it was not possible to record residual part of F_R - Δ_t diagrams.

The differences between residual strengths in bending tests and axial tension test are significantly higher than at macrocracking (table 5). The ratios of values significantly exceed the values, which are defined in documents [3] and [4].

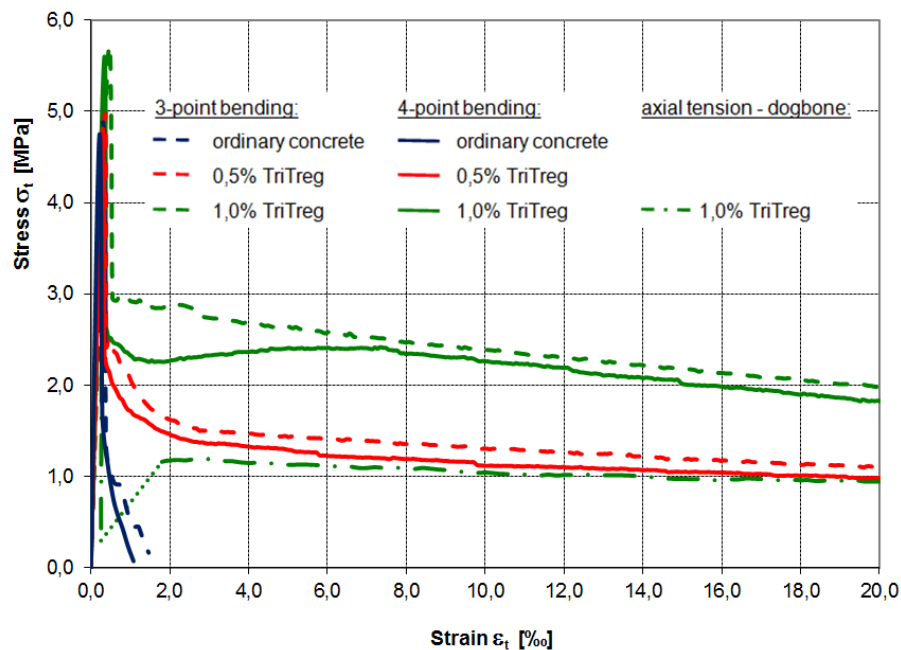


Figure 7. Comparison of stress-strain diagram in 3-point bending test, 4-point bending test and axial tension test - recipes 1, 2, 3

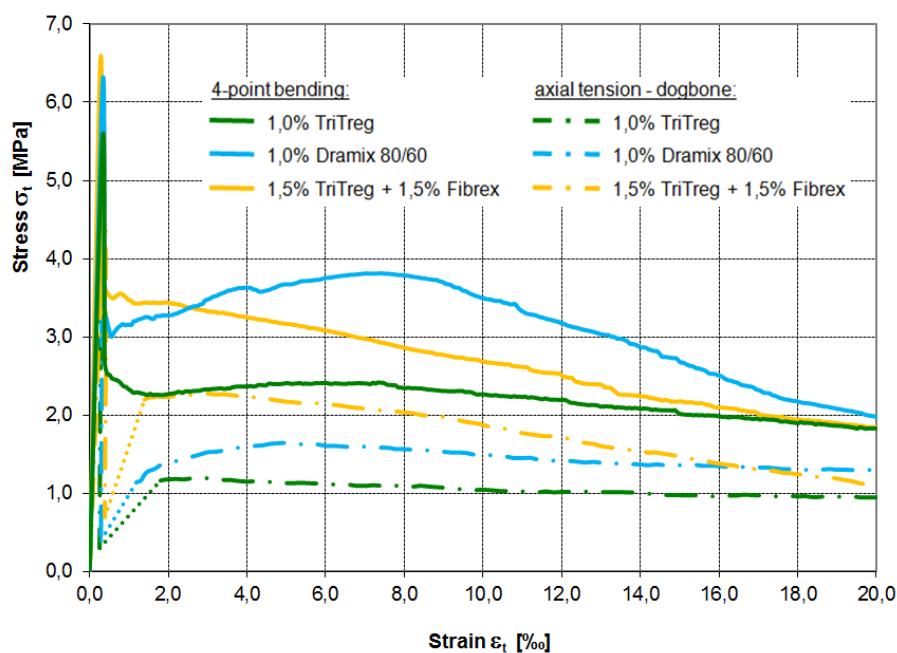


Figure 8. Comparison of stress-strain diagram in 4-point bending test and axial tension test - recipes 3, 4, 5

It was unable to derive parametric conversion relationships for tensile strength in different tests, where the variable parameter would be the value of tensile strain $\epsilon_{t,i}$. An influence of type and dose of fibres isn't also clear and conversion relationships need to be calibrated for each specific composition of cementitious composite separately.

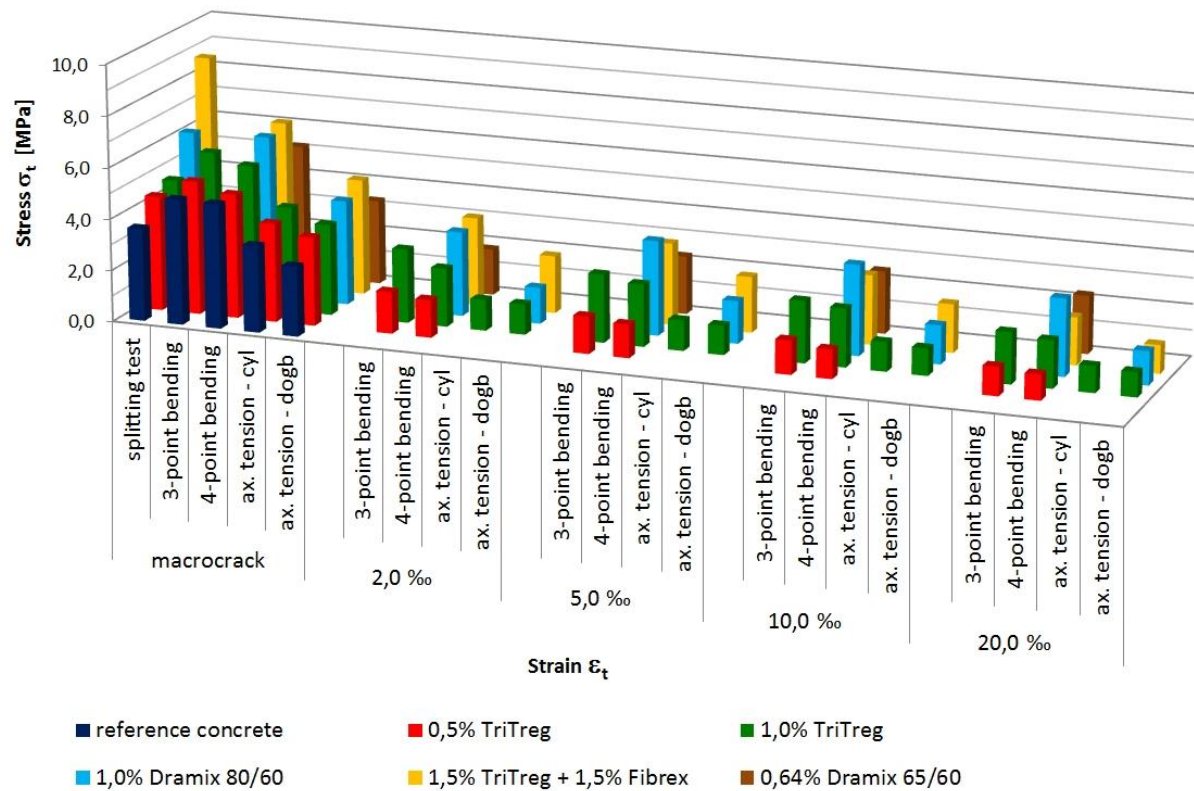


Figure 9. Evaluation of experiments - tensile strength of fibre reinforced concrete

4. Conclusion

The tensile strength of fibre reinforced composites with different recipe in different types of tests was experimentally compared. The outputs are the conversion factors between strengths for specific tested composites. It has been shown that values of conversion factors are different for each recipe and also depends on the value of deformation (both in and after macrocracking). It can be clearly recommended to determine these factors for each specific composition, if the tensile strengths are not tested in axial tension test.

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