Fibre Reinforced Spray Concrete Performance Criteria:

Comparison Between EN 14651 and EFNARC Three Point Bending Test on Square Panel with Notch

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Abstract

The design of Fibre Reinforced Concrete (FRC) tunnels is often made adopting the indication of FIB Model Code. This Model Code is considered as reference document in several guidelines for tunnels.

In order to classify and characterize the FRC in tension, FIB suggests using the EN 14651 bending test. The EN 14651 test is made on beams having a square section 150x150 mm and a length between 550 and 700 mm. This beam geometry is suitable to cast concrete.

The interest on sprayed FRC for permanent applications is now increasing. Sprayed FRC is currently largely used in traditional excavated tunnels, where a temporary lining is cast. Design of temporary sprayed FRC lining is usually made considering the energy values given by EN 14488-5 tests.

EN 14488-5 tests are made on 600x600 mm panel with a thickness of 100 mm.

In order to design permanent structures made with sprayed FRC, it is necessary to make a material characterization (e.g. classification according to Model Code). EN 14651 beam tests can be hardly performed due to the difficulty in preparing specimens with sprayed concrete.

In order to fulfil this need, EFNARC prepared a document suggesting the use of bending tests on panel having the same geometry of EN 14488-5 (600x600x100 mm) and proposing a correlation between EFNARC bending test and EN 14651 bending test.

The analysis of the results of tests, made with the same concrete mixes and adopting EN 14651 and EFNARC tests will be presented in this paper.

Keywords

Fibre testing - Spray concrete - Performance

1 EN14651 BEAM TEST

According to EN14651 requirements, beam tests are performed on beams with nominal square dimensions 150x150 mm and length between 550 and 700 mm (Fig. 1). The cast surface was rotated by 90 degrees, and in correspondence to the midspan, a notch with a maximum width of 5 mm and a height of 25 mm is sawn (Fig. 2). The notch allows the creating of a weak section where crack can spread easily. In this way in correspondence of the notch, the depth of the section is equal to 125mm.

The beam is tested on 3 points load scheme with a span of 500 mm.

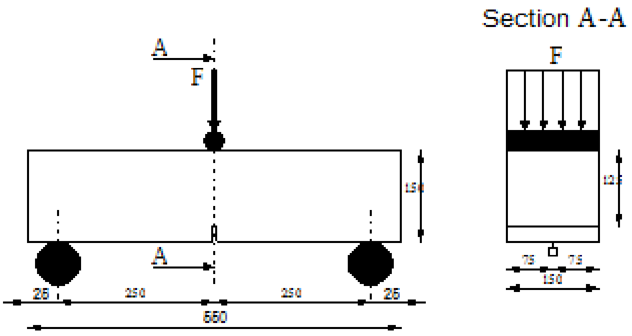

Figure 1. Geometry of EN 14651 specimen.

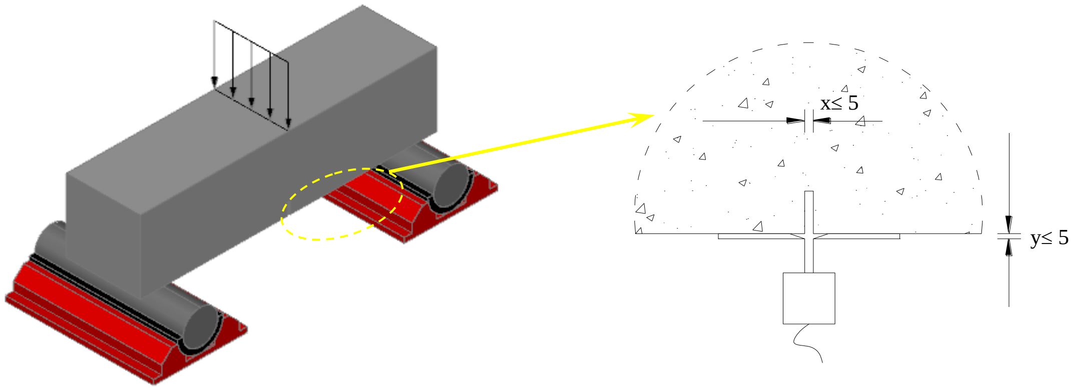

Figure 2. Particular and dimensions of the notch.

The results of the EN 14651 test are the limit of proportionality (LOP) $f_{ct,L}$ and the residual tensile strength f_{R1}, f_{R2}, f_{R3}, f_{R4} evaluated at a crack mouth opening displacement (CMOD) of 0.5, 1.5, 2.5, 3.5 MPa respectively (Fig. 3).

Furthermore, since in some laboratory the tests performed measuring the CMOD could complicated, a relationship between CMOD and beam midspan displacement δ is given (Fig. 4)

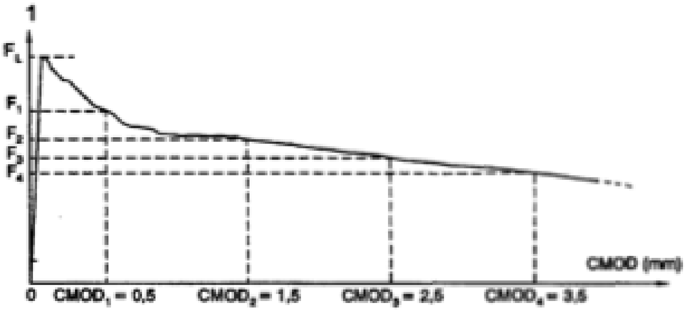

Figure 3. EN 14651 residual strength definition.

Table 1 – Relationship between *CMOD* and *δ*

CMOD (mm)	*δ* (mm)
0,05	0,08
0,1	0,13
0,2	0,21
0,5	0,47
1,5	1,32
2,5	2,17
3,5	3,02
4,0	3,44

Figure 4. EN 14651 relationship between CMOD and midspan displacement δ .

EFNARC BENDING TEST ON PANEL

Test is made on square panel 600 x 600 mm with a thickness of 100 mm. The notch has a high of 10 mm (Fig. 5).

The panels a are placed on a span of 500 mm and tested with a three point bending configuration.

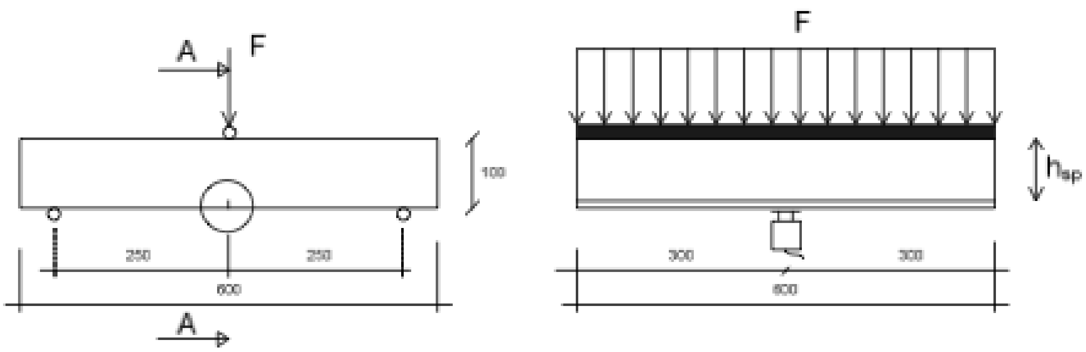

Figure 5. Geometry of EFNARC specimen.

A relationship between panel tests deformation δ and CMOD and the respective δ and CMOD of EN 14651 are given in the EFNARC guidelines in order to have the same results in term of LOP $f_{ct,L}$ and the residual tensile strength f_{R1}, f_{R2}, f_{R3}, f_{R4} (Fig. 6).

	Residual crack strength	CMOD (in mm)	Deflection (in mm)	Crack opening (in mm)
EN14651 beam test	$f_{R,1}$	0.5	0.454	0.409
	$f_{R,2}$	1.5	1.364	1.227
	$f_{R,3}$	2.5	2.273	2.045
	$f_{R,4}$	3.5	3.182	2.864
3 point bending test on square panels with notch of 10 mm	$f_{R,1}$	0.5	0.631	0.409
	$f_{R,2}$	1.5	1.894	1.227
	$f_{R,3}$	2.5	3.156	2.045
	$f_{R,4}$	3.5	4.420	2.864

Figure 6. relationship between EFNARC and EN 14651.

COMPARISON OF THE RESULTS OBTAINED WITH THE TWO TESTING SET-UP

In order to compare the results obtained with EN 14651 and EFNARC tests, an experimental campaign was organised.

Tests were performed in 2 different laboratories: Bekaert Asia R&D Center and K&H GEOTECHNICAL LAB. In total 6 different mixes were prepared, mainly considering different fiber content, different concrete matrix, different type of fibers.

The adopted mixes are summarised in Table 4.1

In Bekaert Asia R&D Center tests 6 beams and 6 panels were cast for every mix whereas in K&H GEOTECHNICAL LAB 12 beams and 12 panels were prepared for every mix.

Table 1. Adopted mixes.

Mix name	Concrete comp. strength [MPa]	Fiber type	Fiber content [kg/m^3]
MIX BEKAERT 1	55.3	4D 65/35BG	25
MIX BEKAERT 2	55.3	4D 65/35BG	40
MIX BEKAERT 3	86.6	4D 65/35BG	25
MIX K&H 1	46.0	4D 65/35BG	25
MIX K&H 2	43.5	4D 65/35BG	40
MIX K&H 3	42.3	5D 65/60	40

Tables 2 and 3 shows the average results in terms of f_L, f_{R1}, f_{R2}, f_{R3}, f_{R4} obtained with EN 14651 and EFNARC.

Table 2. EN14651 average results [MPa].

Mix name	f_L	f_{R1}	f_{R2}	f_{R3}	f_{R4}
MIX BEKAERT 1	5.1	2.7	3.0	2.9	2.6
MIX BEKAERT 2	5.3	3.5	4.0	4.0	3.5
MIX BEKAERT 3	7.6	4.4	4.8	4.0	3.2
MIX K&H 1	3.3	1.7	2.1	2.3	2.1
MIX K&H 2	3.4	2.2	3.2	3.7	3.4
MIX K&H 3	2.9	2.3	3.7	4.3	4.2

Table 3. EN14651 average results [MPa].

Mix name	f_L	f_{R1}	f_{R2}	f_{R3}	f_{R4}
MIX BEKAERT 1	5.2	3.3	3.7	3.5	3.0
MIX BEKAERT 2	5.1	4.2	4.8	4.6	3.9
MIX BEKAERT 3	7.9	4.3	4.6	3.8	3.0
MIX K&H 1	3.4	1.7	2.1	2.1	1.9
MIX K&H 2	3.9	2.6	3.7	3.7	3.5
MIX K&H 3	3.8	2.9	4.5	4.5	4.2

Figure 7 show the ratio between EN 14651 and EFNARC average results for f_L, f_{R1}, f_{R2}, f_{R3}, f_{R4}.

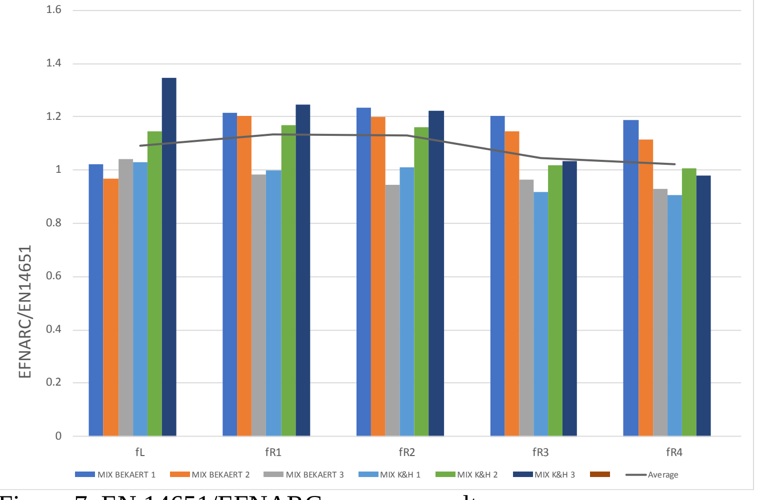

Figure 7. EN 14651/EFNARC average results.

Figure 8 shows the average value for all the mixes of the results presented in Figure 7. It can be noted that the ratio is very close to 1.0 for all the quantities f_L, f_{R1}, f_{R2}, f_{R3}, f_{R4}. This it means that the different between EN 14651 and EFNARC are limited.

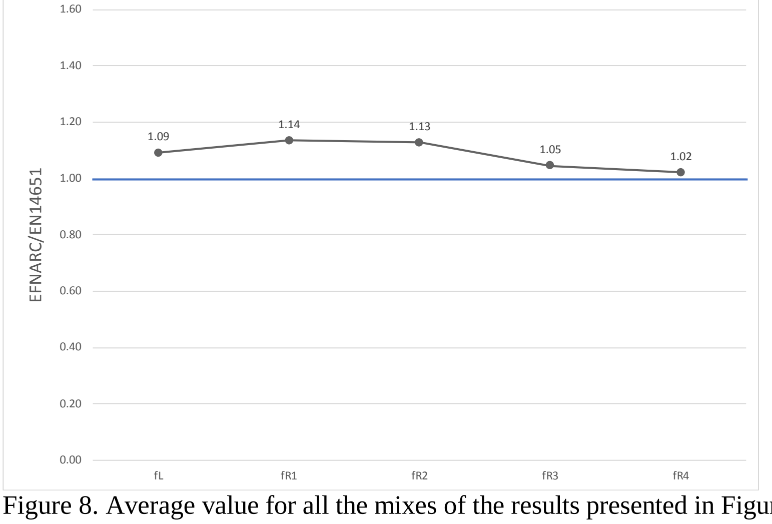

Figure 8. Average value for all the mixes of the results presented in Figure 7

The same analysis id made considering only the three mixes having 25 kg/m^3 of fiber. This is a typical content for sprayed concrete. In this case (Fig. 9) the different between EN 14651 and EFNARC is very limited

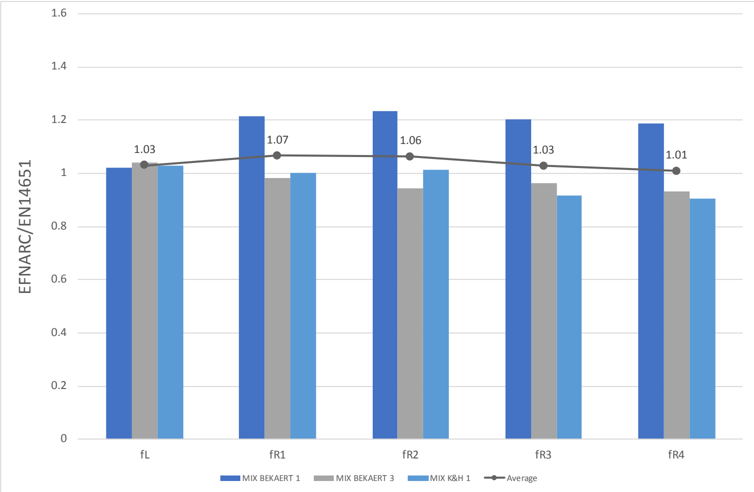

Figure 9. EN 14651/EFNARC average results for mixes with 25 kg/m^3 of fiber

ENFARC test in general give a characterization of fiber reinforced concrete similar to EN 14651. EFNARC results in terms of f_L, f_{R1}, f_{R2}, f_{R3}, f_{R4} are slightly higher respect to the EN 14651: this is probably due to the higher fracture area (almost 3 times higher in EFNARC respect to EN14651).

The aforementioned statement is confirmed by the analysis of the standard deviation and the coefficient of variation of the results. Tables 3 and 4 show the standard deviations and the coefficients of variation of f_L, f_{R1}, f_{R2}, f_{R3}, f_{R4} obtained with EN 14651 and EFNARC.

Table 3. Standard deviation

	EN 14651				
	LOP	CMOD 1	CMOD 2	CMOD 3	CMOD 4
	MPa	MPa	MPa	MPa	MPa
MIX BEKAERT 1	0.14	0.54	0.62	0.63	0.50
MIX BEKAERT 2	0.24	0.65	0.94	0.93	0.73
MIX BEKAERT 3	0.34	0.77	1.00	0.80	0.61
MIX K&H 1	0.91	0.56	0.71	0.76	0.73
MIX K&H 2	0.3	0.7	1.0	1.1	1.0
MIX K&H 3	0.9	0.7	1.1	1.3	1.3
	EFNARC				
	LOP	CMOD 1	CMOD 2	CMOD 3	CMOD 4
	MPa	MPa	MPa	MPa	MPa
MIX BEKAERT 1	0.26	0.4	0.48	0.35	0.23
MIX BEKAERT 2	0.18	0.50	0.66	0.62	0.50
MIX BEKAERT 3	0.46	0.26	0.32	0.29	0.27
MIX K&H 1	0.5	0.3	0.5	0.4	0.4
MIX K&H 2	0.3	0.3	0.5	0.5	0.5
MIX K&H 3	0.3	0.6	0.8	0.8	0.7

Table 4. Coefficient of variation

	EN 14651				
	LOP	CMOD 1	CMOD 2	CMOD 3	CMOD 4
MIX BEKAERT 1	0.03	0.20	0.20	0.22	0.20
MIX BEKAERT 2	0.05	0.19	0.23	0.23	0.21
MIX BEKAERT 3	0.05	0.18	0.21	0.20	0.19
MIX K&H 1	0.28	0.33	0.34	0.33	0.34
MIX K&H 2	0.10	0.31	0.31	0.29	0.30
MIX K&H 3	0.32	0.32	0.31	0.30	0.30

	EFNARC				
	LOP	CMOD 1	CMOD 2	CMOD 3	CMOD 4
MIX BEKAERT 1	0.05	0.12	0.13	0.10	0.08
MIX BEKAERT 2	0.04	0.12	0.14	0.14	0.13
MIX BEKAERT 3	0.06	0.06	0.07	0.08	0.09
MIX K&H 1	0.16	0.19	0.22	0.21	0.21
MIX K&H 2	0.07	0.13	0.13	0.14	0.14
MIX K&H 3	0.08	0.21	0.19	0.17	0.16

Figure 10 shows the ratio between EN 14651 and EFNARC coefficient of variation results for f_L, f_{R1}, f_{R2}, f_{R3}, f_{R4}. It can be noted as the coefficient of variation for f_{R1}, f_{R2}, f_{R3}, f_{R4} are remarkably lower for EFNARC tests.

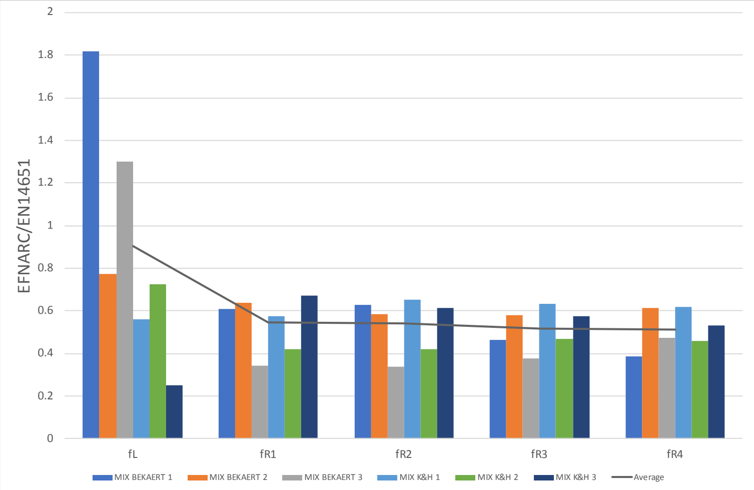

Figure 10. Ratio between EN 14651 and EFNARC coefficient of variation results

CONCLUSIONS

ENFARC test appears to be a suitable for characterizing sprayed fiber reinforced concrete.

The specimen adopted in EFNARC can be easily prepared with spay concrete since the same moulds for EN 14488-5 can be used. It has to remark that beams with the geometry proposed in EN 14651 are difficult to prepare with sprayed concrete and should not be representative of the actual material properties.

The results presented in the report show that the differences between EFNARC and EN 14651 results are very close. The characterization of a fiber reinforced concrete made with EFNARC is similar to what obtained with EN 14651 beam tests. This is particularly evident for fiber content typically adopted in sprayed concrete.

The results obtained with EFNARC test can be used for the characterization of sprayed fiber reinforced concrete as demonstrated by the results of the laboratories tests.

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