VARIATION OF STEEL-FIBRE CONCRETE PARAMETERS DEPENDING ON THE MIXING PROCEDURE

VÍTEK Jan L. [1], SMIŘINSKÝ Stanislav [2], VESELÝ Pavel [3], VESELÝ Vladimír [4]

Abstract

Mixing of fibre reinforced concrete is an important parameter influencing its mechanical parameters. An experimental research was carried out in order to investigate the effect of mixing on the concrete mix with two different types of fibres. Mixing time, type of fibres and amount of fibres were combined in 18 alternatives. The properties of fresh and hardened concrete were evaluated.

Keywords: Concrete, fibres, mixing time, strength, modulus of elasticity.

1. Introduction

Fibre reinforced concrete is produced for many years. Its application can be found preferably in industrial floors, precast tunnel linings and other structures. In spite of the long term production the homogeneity of fibre reinforced concrete is not completely uniform. It results in the relatively large scatter of its mechanical parameters; in particular the tensile behaviour may significantly differ at completely identical concrete mixes. It would be very appreciated if this scatter would be reduced. The experiment was carried out in order to investigate the influence of the type of fibres and the influence o the mixing time of the statistical scatter of the mechanical parameters and workability of fibre reinforced concrete.

2. Description of the experiment

The objective of the experiment was to verify the performance usual fibre reinforced concrete which is used for industrial floors and other structural elements. Only steel fibres were used. The variable parameters were the type of fibres, the dosage of fibres and the mixing times. The type of fibres and their dosage influenced also the dosage of the

[1] VÍTEK Jan L., Metrostav a.s. Koželužská 2246, 180 00 Praha 8, vitek@metrostav.cz

[2] SMIŘINSKÝ Stanislav, BETOTECH, s.r.o Beroun 660, 266 01 Beroun, stanislav.smirinsky@betotech.cz

[3] VESELÝ Pavel, BETOTECH, s.r.o Beroun 660, 266 01 Beroun, pavel.vesely@betotech.cz

[4] VESELÝ Vladimír, BETOTECH, s.r.o Beroun 660, 266 01 Beroun, vladimir.vesely@betotech.cz

superplasticizer. For the evaluation of properties of fresh concrete and hardened concrete, the usual generally recognized testing methods were used.

2.1 Composition of fibre reinforced concrete

The constituents which are available at usual mixing plants were selected for the experiment. The concrete was designed according to the EN 206-1 satisfying the strength class C35/45, with maximum aggregate size 16 mm and the workability F5. The composition and the granulometry of the aggregate were designed with regard to the fibre contents. The consistency and the water cement ratio should have been almost identical in all mixes. The concrete was composed of the cement CEM III/B 32.5 (400 kg/m^3), 3 fractions of aggregate, flying ash (120 kg/m^3), and superplasticizer. The water cement ratio was about 0.42.

The 2 types of fibres were used. a) Fibres DE 30/0.8 ROT with the aspect ratio 37.5 and b) Fibres DE 50/1 with the aspect ratio 50. The fibres were added into the mixer at the mixing plant.

2.2 Mixing procedure

The mixing procedure was designed similarly to that used at the usual mixing plant. The conditions for individual mixes were completely identical. The loss of workability, when the content of fibres was increased, was balanced by modification of the superplasticizer dosage. First the concrete without fibres was mixed for a period of 55 s at all mixes. Then the fibres were added and the mixing continued for a period of 30, 90 or 180 s. Then the mixer was emptied and the concrete was put into the vessel of the vehicle. The fibre content in fresh concrete was then tested. The specimens were taken from the lower part and form the upper part of the vessel content. Then the workability was measured. Finally the specimens for tests on the hardened concrete were produced. The concrete was taken in sequence form the middle part, prom the left hand side and right hand side of the vessel.

3. Results of the tests

3.1 Testing of fresh concrete

The fibre content of in fresh concrete is the most important result of the fresh concrete tests. The results are summarized in the Table no. 1. Column no. 4 shows the result of the slump flow test and col. no. 6 the specific weight of fresh concrete. The results vary according to the fibre content (col. no. 2). The fibre content measured twice in each mix is printed in the last three columns of the Table no. 1.

Workability varies primarily in dependence on the fibre content. The fibres form an obstacle for free flowing of concrete, i.e. the higher fibre content, the lower flowability. These results were obtained in spite of the variable dosage of the superplasticizer, which should eliminate this effect.

The drop of the specific weight of the fresh concrete in longer mixed concrete in some cases may be a result of higher air content on concrete due to longer mixing.

The fibre content was measured by a special device called Profometer. The strong magnetic field separates the fibres from the specimen of concrete. It has been shown that the content of shorter fibres roughly corresponds to the expected fibre content. On the other hand the measured content of longer fibres was systematically lower than the content

Tab.1: Measured parameters of the fresh fibre reinforced concrete

1.	2.	3.	4.	5.	6.	7.		
Type of the steel fibres	Dosage of steel fibres [kg/m3]	Mixing time [s]	Slump – flow diameter [mm]	Temperature of the fresh fibre concr. [°C]	Volumetric density of fresh fibre concr. [kg/m3]	Fibre content in fresh concrete		
						Measured 1 [kg/m3]	Measured 2 [kg/m3]	Average [kg/m3]
DE 30/0,8 ROT	30	30	660	17.2	2319	28.1	32.8	30.5
DE 30/0,8 ROT	30	90	660	17.1	2280	25.7	29.5	27.6
DE 30/0,8 ROT	30	180	600	17.6	2264	26.4	28.0	27.2
DE 30/0,8 ROT	50	30	605	17.6	2304	58.7	52.9	55.8
DE 30/0,8 ROT	50	90	550	18.1	2267	51.2	51.6	51.4
DE 30/0,8 ROT	50	180	640	18.0	2267	48.9	53.2	51.1
DE 30/0,8 ROT	70	30	570	16.8	2305	72.9	73.8	73.4
DE 30/0,8 ROT	70	90	560	17.1	2317	71.5	73.2	72.4
DE 30/0,8 ROT	70	180	510	16.5	2289	74.5	75.1	74.8
DE 50/1,0 N	30	30	600	17.3	2323	26.2	29.1	27.7
DE 50/1,0 N	30	90	660	18.3	2298	24.8	29.8	27.3
DE 50/1,0 N	30	180	570	16.9	2308	23.0	31.0	27.0
DE 50/1,0 N	50	30	630	17.3	2287	43.8	61.2	52.5
DE 50/1,0 N	50	90	600	17.3	2289	45.9	51.2	48.6
DE 50/1,0 N	50	180	460	16.9	2284	43.4	43.5	43.5
DE 50/1,0 N	70	30	565	16.7	2300	58.9	73.0	66.0
DE 50/1,0 N	70	90	530	17.2	2309	60.1	65.9	63.0
DE 50/1,0 N	70	180	615	17.4	2282	57.9	73.7	65.8

expected. The reason can be found in a small specimen selected for measurement. The number of longer fibres in a volume unit is smaller and then the error of measurement may become higher. However, it is also possible, that the Profometer is not able to separate all the fibres in the specimen, since they are better anchored in the fresh concrete. The results seem to be uniform which allows for a confidence that the measured fibre contents are similar in different parts of the vessel.

3.2 Testing of hardened concrete

In hardened concrete the fibre content was again measured and then the strength in compression and in tension and finally the modulus of elasticity were observed. The review of all tests in illustrated in the Table no. 2.

The fibre content in hardened concrete was measured using a method called BSM 100. It a non destructive method which measures the fibre content in three steps, when the cube is inserted into the machine in three different directions. In order to check the correct function of the BSM 100 method, two cubes were crushed and the number of fibres was counted. The comparison of the fibre content obtained by BSM 100 method and from the crushed cube is illustrated in the Table no.3. Relatively good agreement was obtained, although the fibre content is about 10 kg/m^3 lower than the expected fibre content. Such result is possible because of the cube (150 mm) is very small in comparison with the 1m^3. The measured volume represents only 0.34% of the reference volume (1 m^3).

Tab.2: Measured parameters of the hardened fibre reinforced concrete

1.	2.	3.	4.	5.	6.	7.	8.
Type of steel fibres	Dosage of steel fibres	Mixing time	Measured fibre content	Compressive strength – cubes	Splitting tensile strenght of concrete – cubes	Static modul of elasticity in compression - cylinders	Average flexural tensile strenght of concrete
	[kg/m3]	[s]	[kg/m3]	[MPa]	[MPa]	[GPa]	[MPa]
DE 30/0,8 ROT	30	30	36.9	56.8	4.4	29.5	4.0
DE 30/0,8 ROT	30	90	36.7	54.6	3.7	29.0	4.4
DE 30/0,8 ROT	30	180	33.9	47.5	3.5	28.5	4.7
DE 30/0,8 ROT	50	30	52.9	51.4	4.0	30.0	5.3
DE 30/0,8 ROT	50	90	44.1	50.2	3.9	29.5	5.0
DE 30/0,8 ROT	50	180	60.3	51.3	3.9	26.5	4.3
DE 30/0,8 ROT	70	30	60.7	53.3	3.5	28.5	5.0
DE 30/0,8 ROT	70	90	62.1	52.1	3.7	28.5	5.3
DE 30/0,8 ROT	70	180	60.4	49.9	3.4	29.5	5.1
DE 50/1,0 N	30	30	23.3	52.7	3.5	28.0	5.2
DE 50/1,0 N	30	90	24.2	56.4	3.9	32.0	5.2
DE 50/1,0 N	30	180	26.9	44.6	3.4	27.5	4.2
DE 50/1,0 N	50	30	41.5	49.0	4.0	28.0	4.9
DE 50/1,0 N	50	90	42.8	47.8	3.9	28.0	4.9
DE 50/1,0 N	50	180	43.5	46.4	3.8	26.0	4.7
DE 50/1,0 N	70	30	58.7	51.3	4.1	30.0	4.7
DE 50/1,0 N	70	90	59.2	48.3	4.1	28.0	5.3
DE 50/1,0 N	70	180	65.1	47.4	5.0	28.0	5.3

Tab.3: Comparison of the fibre content measured by BSM 100 and in crushed cube

1.	2.	3.	4.
Branding of speciment	Dosage of fibres meassured by BSM 100 method	Directly counted dosage of fibres from the crushed speciment - cube	Difference
	[kg/m3]	[kg/m3]	in %
3/4/30/50/30	20.6	19.0	8.4
15/4/90/30/70	62.0	64.6	-4.0

The measured cube compression strength varies in the range 46.4 – 56.8 MPa. The results are plotted in Fig. 1. Minor reduction was observed at the concrete with longer fibres hire fibre contents.

The splitting tensile strength was measured on cubes 150 mm. The measured values are very close each other; they represent the averages from 3 specimens. The differences are given rather by the statistical scatter than by the physical phenomenon. Only the strength of the specimens with 70 kg long fibres exhibit slightly higher values (Fig. 2)

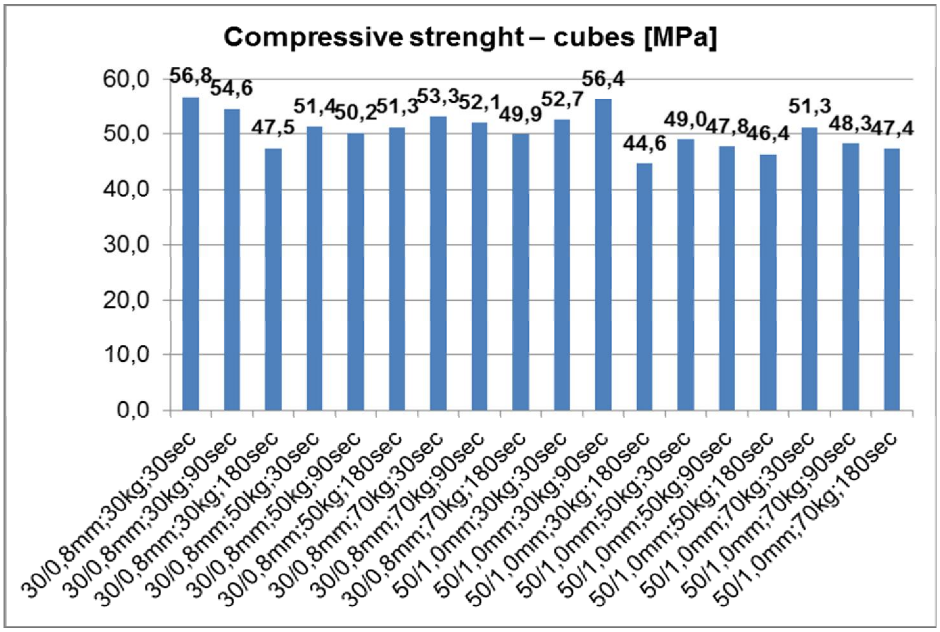

Fig. 1: Measured cube compressive strength (average values from 3 specimens)

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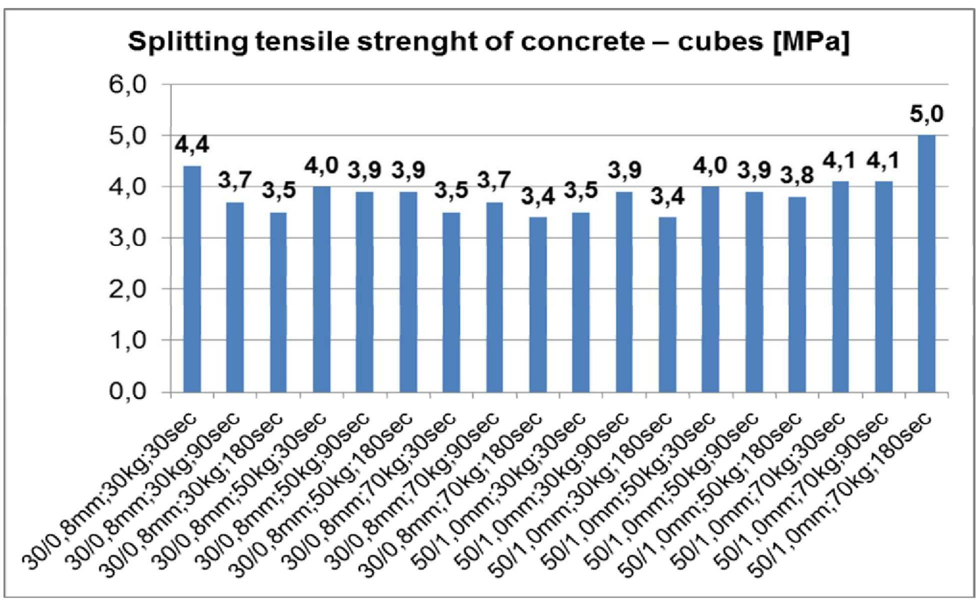

Fig. 2: Measured splitting tensile strength (average values from 3 specimens)

Modulus of elasticity was measured on standard cylinders (150 x 300 mm). The presented values are average values from 2 measurements (Fig. 3). The values are very similar and the fibre content as well as the mixing time had almost no effect on the measured moduli. However, it is necessary to note that all measured values (in the range from 27 to 32 GPa) are significantly smaller than the values assumed in Eurocode 1992-1-1 (34 GPa).

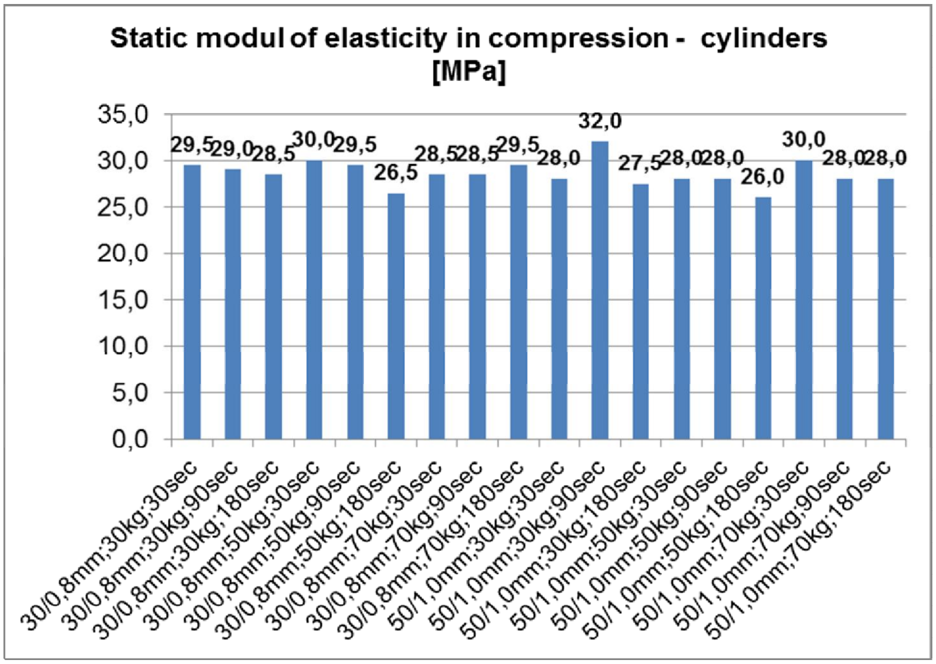

Fig. 3: Measured modulus of elasticity in compression (average values from 2 specimens)

The behaviour of fibre reinforced concrete in bending was investigated using the four point bending tests on the beams 150 x 150 x 700 mm with the span 600 mm without notch. The test arrangement is plotted in Figs. 4 and 5. The loading was controlled by deflection. The average speed of deflection growth was settled to 0.2 mm/s. The position of the main crack from the left hand side support was also measured. The load deflection diagrams are plotted in Fig. 6 (short fibres – 30 mm) and in Fig. 7 (long fibres – 50 mm). The illustrated lines represent average values from 6 beams subjected to the test.

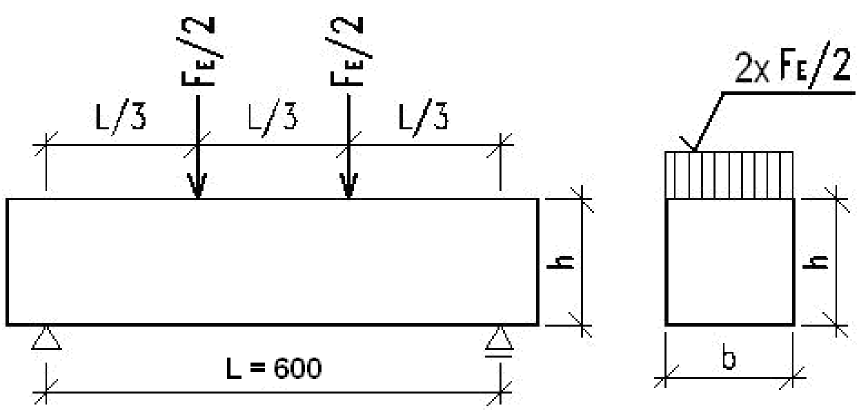

Fig. 4: Four point bending test arrangement

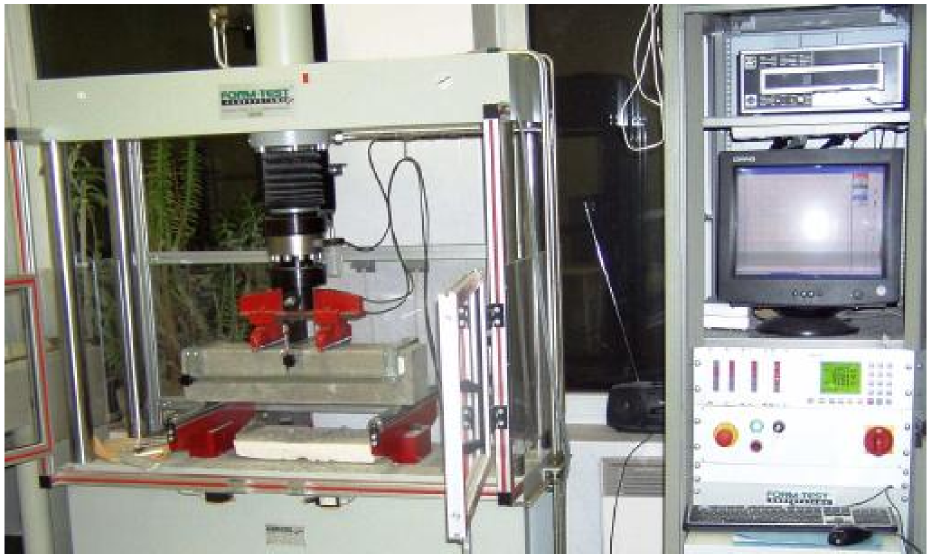

Fig. 5: Photograph of the four point bending test and the measuring equipment

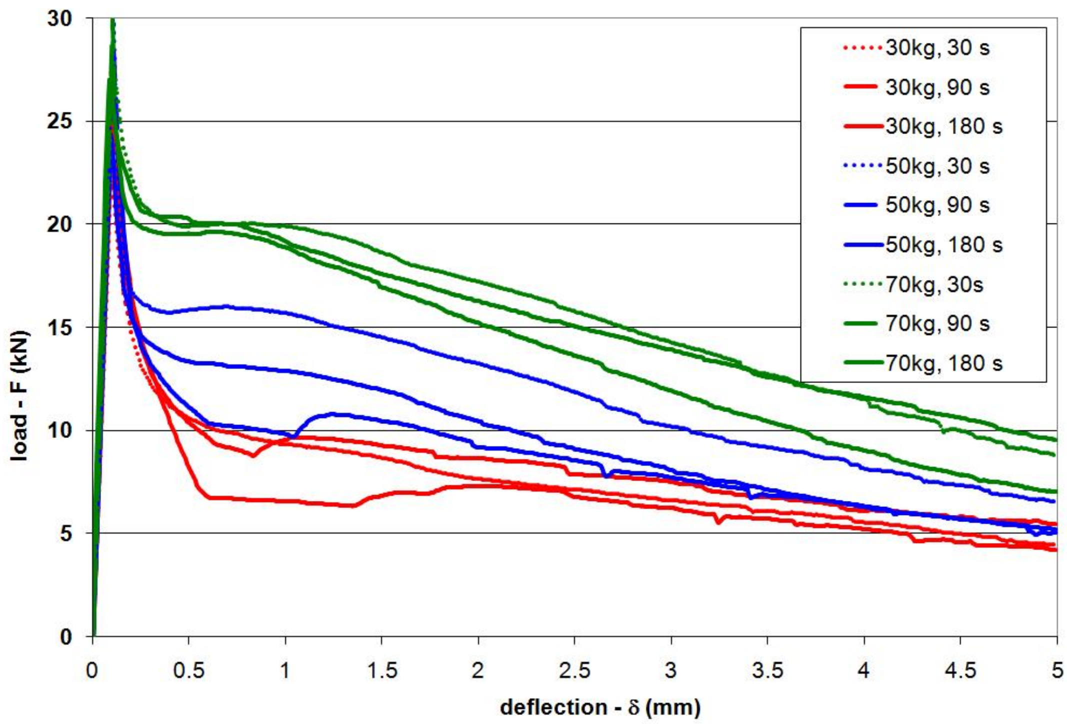

Fig. 6: Load deflection diagram – FRC with short fibres (30/0.8 mm)

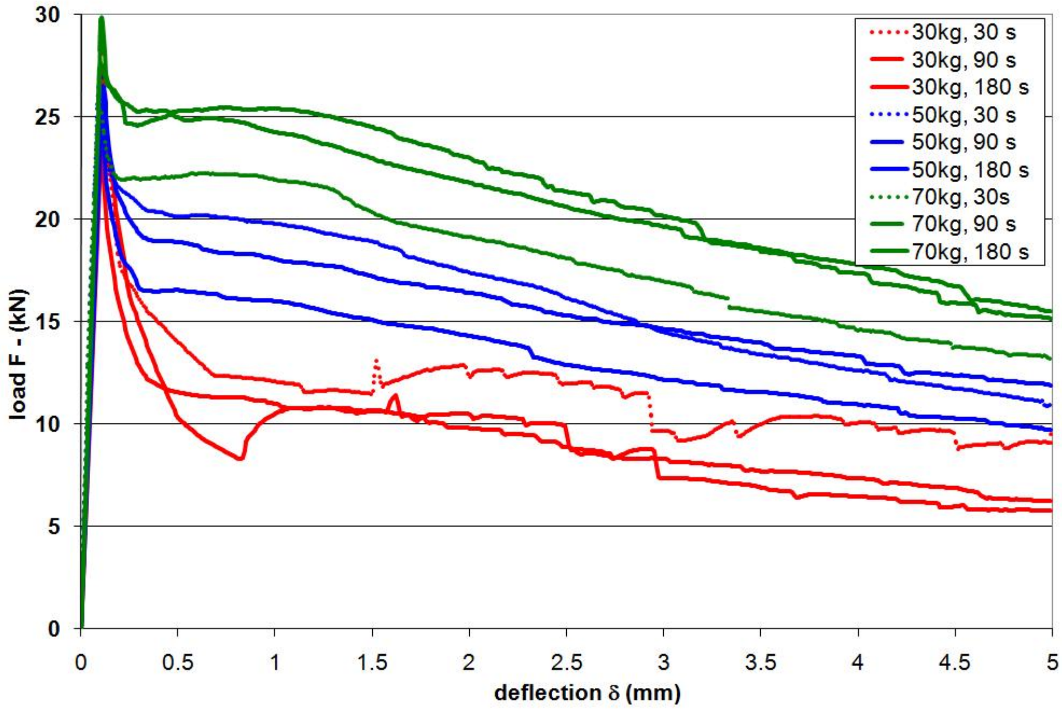

Fig. 7: Load deflection diagram – FRC with long fibres (50/1 mm)

The complete set of beams tested on bending comprised 108 beams. From those 8 beams collapsed immediately after cracking, i.e. no descending branch was recorded.

The bending tests showed that the longer fibres provide better performance, higher residual strength than the shorter fibres. On the other hand the shorter fibres exhibit smaller scatter especially if 70 kg/m^3 fibres is used.

Figs. 8 and 9 show the effect of the mixing time and fibre content on the residual strength in bending (at the deflection of 3.5 mm). The residual strength of fibre reinforced concrete with short fibres is higher if the mixing time is shorter. On the other hand at longer fibres the same conclusion was found only for the lowest fibre content (30 kg/m^3). For fibre reinforced concrete with long fibres the longer mixing time was favourable. Although a large set of experiments was carried out the unique conclusion confirming the effect of the mixing time was not found.

4. Conclusions

Although the testing was from the beginning very carefully executed there are some unfavourable effects which cannot be avoided. The consistency which should be very similar is influenced by the dosage of superplasticizer. The longer mixing time increases the efficiency of superplasticizer. In spite of these effects the conditions for mixing of fibres into the concrete remained very similar.

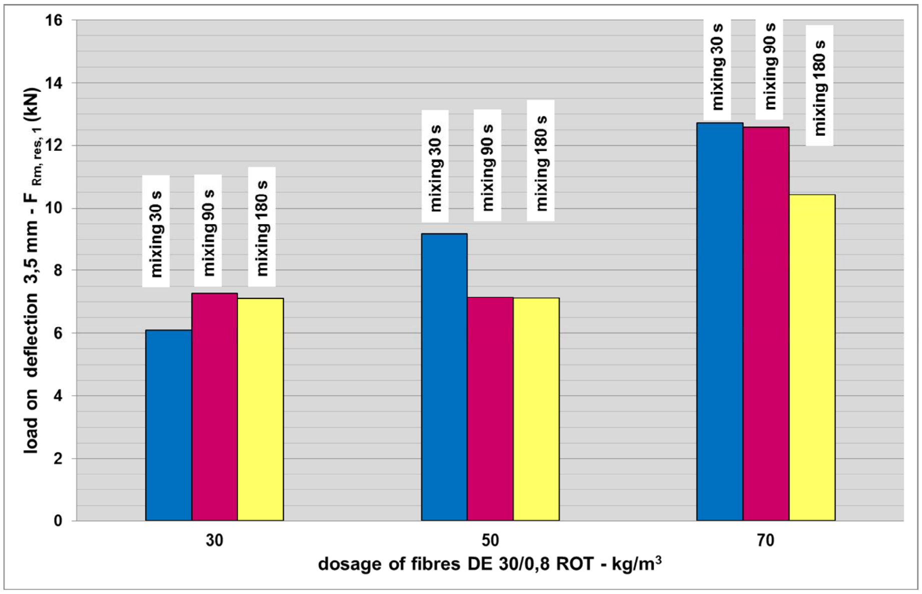

Fig. 8: Effect of mixing time and fibre content on the residual bending strength (at the defl. 3.5 mm) – short fibres

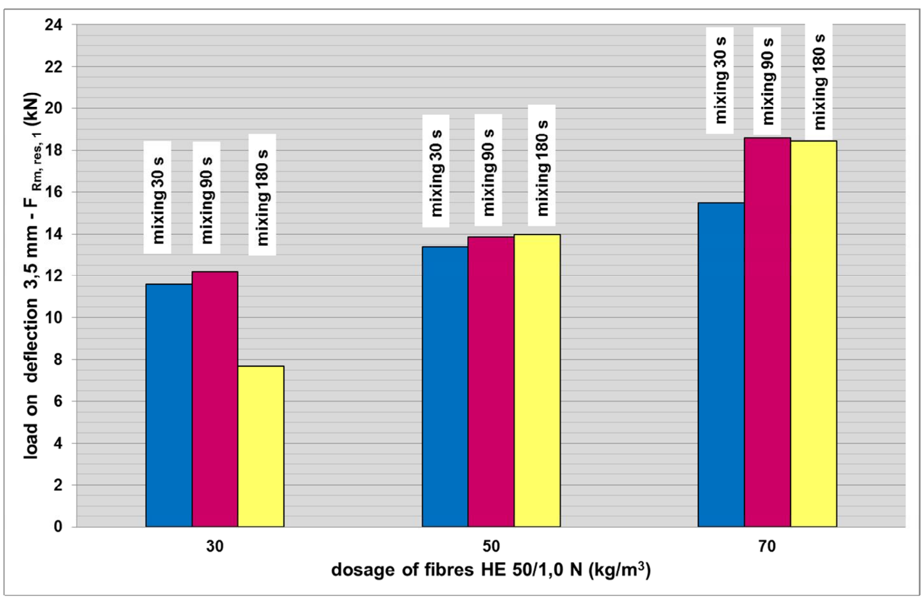

Fig. 9: Effect of mixing time and fibre content on the residual bending strength (at the defl. 3.5 mm) – long fibres

The content of fibres in fresh concrete measured by Profometer provided relatively good results. In the case of short fibres the deviation was in average +5%, in the case of long fibres the deviation varied between -13% and + 5%. The Profometer may be taken as sufficiently reliable method for checking of fibre content in fresh concrete.

The method BSM 100 provided good results, although the method is not codified. It allows for observation of the fibre arrangement in the different directions. It may be recommended for application in practice. On the other hand the method of crushing of the cube provides more exact results, but the distribution of fibres in different directions cannot be specified.

The favourable effect of the mixing time on the concrete strength in compression, tension and bending was not proven. Some trend was observed only at FRC with long fibres at the residual bending strength.

The bending tests showed, as in could be expected, increasing resistance with increasing fibre content. However, the scatter at FRC with longer fibres was larger than that at FRC with shorter fibres. The measurement of the area under the curve of the load deflection diagram showed that in 90% from the observed 18 alternatives, the best results were achieved at the mixing time 30 s. The reason is hard to explain.

The results showed, that although all the activities were executed very carefully, the scatter of the results at all tested alternatives was not avoided. The number of fibres is not large enough so that the homogeneous mix could be produced. If real conditions on the site are taken into account it seems to be inevitable to get a scatter in properties of FRC. Therefore it seems to be necessary to define a certain scatter which will be considered in the design of structures and which will guarantee a reliable design of fibre reinforced structures.

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