

EFFECT OF FIBRE ORIENTATION ON THE TOUGHNESS PROPERTIES OF STEEL FIBRE REINFORCED CONCRETE

INTRODUCTION

World-wide, application of fibre reinforced composite materials are growing rapidly due to their high performances. Nowadays, fibre reinforced composites are widely used from the space industry (Fibre Reinforced Polymers = FRP) to the civil engineering (Fibre Reinforced Concrete = FRC). Improvement of the properties of materials applying fibre reinforcement is not a new idea. Historically, short fibres have been used to reinforce brittle matrices since ancient times. Fibres are effectively used to improve tensile strength in case of FRP, toughness, ductility and impact resistance of the matrix in case of FRC [1 to 10].

Generally, fibres in the matrix material are placed industrially and oriented in different directions. Therefore, Glass Reinforced Plastics (GRP) and Carbon Fibre Reinforced Plastics has well defined anisotropic properties. Steel fibre reinforced concrete represents a special type of fibre reinforced composite materials since the fibre orientation is random due to the mixing process of the concrete. However, depending on the structural element where FRC used and on the technology of their concreting fibres are oriented resulting anisotropy.

This paper deals with an experimental investigation to study the effect of fibre orientation on the most important properties of steel fibre reinforced concrete namely the toughness. Different approaches are also studied to determine the so-called toughness indexes.

EXPERIMENTAL PROGRAM

Concrete mix

In Tables 1 concrete mix proportions are summarised. Concrete mixes typified by their notations. They will be used in the following when referring to the mix a specimen made from. Four types of concrete mixes were designed. FRC denotes the "Fibre Reinforced Concrete". The superscript and subscript indices denote the content of fibre weight (75 kg/m^3 , 150 kg/m^3) and the type of fibre (Dramix³ ZP 305), respectively.

Table 1: Concrete composition in dry material [kg/m^3]

Notation of mix	Fine aggregates		Cement	Super-plasticizer	Water to cement ratio	Fibre Content
	0-4	4-8				
	mm	mm				
1 FRC-1 ⁷⁵ _{ZP 305}	1056	829	330	5,952	0,512	75
2 FRC-1 ¹⁵⁰ _{ZP 305}	1056	829	330	8,571	0,512	150
3 FRC-2 ⁷⁵ _{ZP 205}	958	752	500	9,048	0,372	75
4 FRC-2 ¹⁵⁰ _{ZP 305}	958	752	500	10,476	0,372	150

The mixtures contain only fine aggregates. Two washed and classified fine aggregate fractions were used, 0-4 mm sandy-gravel and 4-8 mm gravel fractions. The maximum aggregate diameter therefore was 8 mm. The concrete mixes made of pure Portland Cement, Hungarian Portland Cement CEM I, 52.5 (550 pc) was used.

Proper workability was obtained by the addition of superplasticizer in order to reduce the water to cement ratio. The superplasticizer was SIKAMENT-10 HBR.

Concrete mixes were produced at the Laboratory of the Department of Reinforced Concrete Structures, Technical University of Budapest. Due to the strongly constrained capacity of the concrete mixer and the rapid hydration of the Portland Cement each test specimens were cast independently with the same mixture proportions.

The mixing process of concrete containing fibre reinforcement is well discussed in the literature. Numerous publications and recommendations have already been treated with this topic. In the present research the mixing procedure

starts with blending of the fine aggregates followed by addition of cement. In all cases the fibres were dry mixed with the aggregates and cement before adding the water and the superplasticizer. The superplasticizer dispersed in a portion of water is poured into the mixture and finally the remaining water is supplied successively, until a good workability is observed in the concrete. The redundant water, if any, is weighted and thus the mixing proportions have been slightly modified as shown in Table 1.


During the mixing and casting as well there was no any change in workability. However, in case of concrete mixes noted FRC-2 due to their relatively higher superplasticizer content, lower energy was needed to mix and cast them.

Type of fibres

Metallic fibres were used for all mixtures since many earlier studies showed polymer fibres does not have significant effects on the structural performances of concrete.

Dramix[®] [11] hooked-ends fibres were applied for the mixes noted by FRC-1⁷⁵_{ZP 305} (1), FRC-1¹⁵⁰_{ZP 305} (2), FRC-2⁷⁵_{ZP 305} (3), FRC-2¹⁵⁰_{ZP 305} (4). The configurations and other data of the chosen fibres are summarised in Table 2.

Table 2: Used type of fibres and their mechanical properties

Notation	Material type	Shape	Aspect ratio l/d_f	Density kg/m ³	Strength MPa	Elastic modulus GPa
Dramix [®] ZP 305	Steel		60	7800	1100	200

Dramix[®] fibres are made with hooked-ends as can be seen on Photo 1. They are delivered as bundles of fibres glued together with a rapid resolved adhesive. Since the fibres form small plates in the mix they behave as flat aggregates during the mixture until the glue resolves resulting homogenous fibre dispersion. It was also observable when fibres was added to the dry mixture of cement and aggregates that the coarser aggregates crushed the plats of glued fibres resulting two or three smaller tables giving more homogenous dry mixture. When water and superplasticizer were introduced into the mix after resolving the glue due to the mentioned smaller plats the mix showed perfect homogeneity without the so called "balling effect".

Since the aim of the tests was to characterise the mechanical properties of SFRC as structural material, two relatively high fibre dosages were introduced into the mixtures despite of the fibre content used in the conventional applications ($20\text{--}40\text{ kg/m}^3$), 75 kg/m^3 ($\sim 1.0\text{ V\%}$) and 150 kg/m^3 ($\sim 2.0\text{ V\%}$) fibre contents were applied. They have already appeared in the superscripts of the mixes (Table 1).

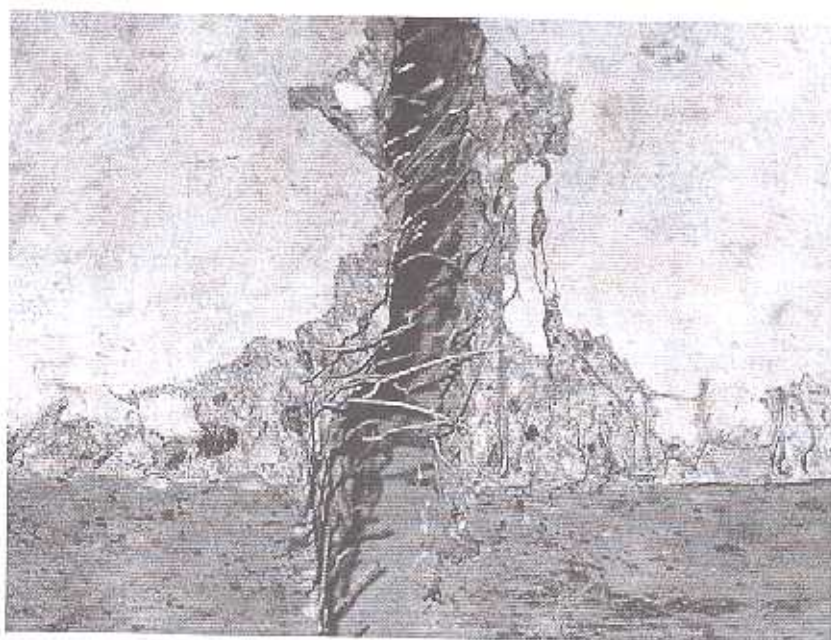


Photo 1: Shape of Dramix[®] ZP 305 in a cracked section

Formworks and test specimens

For all concrete compositions detailed in Table 1 a series of formwork were prepared (Table 3).

Specimen and its geometrical parameters are summarised in Figure 1. One of them has a size of $800 \times 500 \times 100\text{ mm}$ and the other one $820 \times 630 \times 80\text{ mm}$, noted by "A" and "B", respectively.

These geometrical data were determined according to the designed drilled specimens and the capacity of the available concrete mixer.

Roman numbers in the subscript "I." and "II." denote the considered privilege fibre orientation, respectively. Besides the concrete mix proportions and the fibre content, fibre orientation, the major experimental variable of test determining and characterising the mechanical properties and characteristics of

steel fibre reinforced concrete. This parameter plays an important role in the anisotropic behaviour of material, therefore, it is quite essential in structural analysis. For this reason, the privilege fibre orientation was systematically introduced in the material by a P14 type handy vibrator which had a diameter of 28 mm. In specimens denoted "I." and "II.", the privilege fibre orientation was perpendicular on each other. It was formed by moving the vibrator head only in one direction in the specimens noted "I.", and respectively in "II".

Table 3: Type and piece of specimens

Notation of mix		A ¹	B ²
1	FRC-1 ⁷⁵ _{ZP-305} -I	1	1
	FRC-1 ⁷⁵ _{ZP-305} -II	1	1
2	FRC-1 ¹⁷⁵ _{ZP-305} -I	1	1
	FRC-1 ¹⁷⁵ _{ZP-305} -II	1	1
3	FRC-2 ⁷⁵ _{ZP-305} -I	1	1
	FRC-2 ⁷⁵ _{ZP-305} -II	1	1
4	FRC-2 ¹⁷⁵ _{ZP-305} -I	1	1
	FRC-2 ¹⁷⁵ _{ZP-305} -II	1	1

¹ Slab form formwork with a geometry of 800x500x100 mm

² Slab form formwork with a geometry of 820x630x80 mm

After a week of concreting "A", "B" specimens were drilled out of them. The drilling plan is summarised in Table 4.

From specimen "A", 12 prisms with the size of 240x100x100 mm and a small deep beam element with a size of 500x170x100 mm were cut out. They are denoted by "T1"... "T6", "C1"... "C6" and, "DB-a", respectively. In case of prisms "T" indicates that the prism tested in uniaxial direct tensile test while "C" denotes the compressive test. Notation "DB-a" notes the "a" type deep beam element. Specimens "B" were divided into four portions.

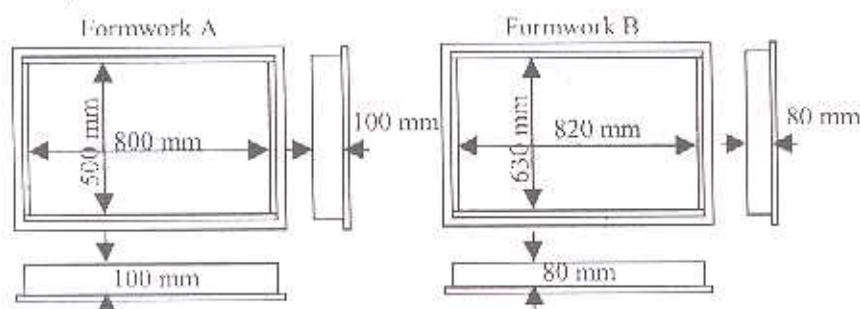


Figure 1: Type of formworks and their geometry

Three of them are beams with the same geometrical parameters $820 \times 85 \times 80$ mm noted by "B-a", "B-b" and "B-c" which respectively indicate three different positions in the formwork. The fourth one is a deep beam specimens denoted by "DB-b" and has a geometry of $820 \times 340 \times 80$ mm. Test of deep beam elements are not discussed here.

Table 4: Drilling plan of specimens related to one concrete composition

Notation of privilege fibre orientation		I.	II.																																								
Privilege fibre orientation																																											
A.	Type of specimen	<table border="1"><tr><td>C</td><td>T</td><td>T</td><td>T</td><td></td></tr><tr><td>T</td><td>C</td><td>C</td><td>C</td><td></td></tr><tr><td>C</td><td>T</td><td>T</td><td>T</td><td></td></tr><tr><td></td><td>C</td><td>C</td><td>C</td><td>DB-</td></tr></table>	C	T	T	T		T	C	C	C		C	T	T	T			C	C	C	DB-	<table border="1"><tr><td>C</td><td>T</td><td>T</td><td>T</td><td></td></tr><tr><td>T</td><td>C</td><td>C</td><td>C</td><td></td></tr><tr><td>C</td><td>T</td><td>T</td><td>T</td><td></td></tr><tr><td></td><td>C</td><td>C</td><td>C</td><td>DB-</td></tr></table>	C	T	T	T		T	C	C	C		C	T	T	T			C	C	C	DB-
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MECHANICAL PROPERTIES OF SFRC BASED ON EXPERIMENTS

Compressive test specimens and testing procedure

It is common that concrete classes are categorised according to their compressive strength. In many countries, the compressive strength generally determined on cubes with the geometry of $150 \times 150 \times 150$ mm. However, classification of concrete is based on cylinder test with the geometry of $\varnothing = 150$ mm, $h = 300$ mm in many recommendation and national codes i.e. EUROCODE-2, CEB-FIP Model Code 90 and in the Hungarian National Code as well.

Other compressive tests related to concrete composition FRC-1 and FRC-2 were carried out at very different period after casting. For this reason and for the comparing of the results, their strength were calculated to 28 days strength according to Weber [12].

As discussed before, 6-6 prism (240×100×100 mm) specimens were drilled-out of the slab element denoted by "A" made from mixes FRC-1 and FRC-2 in order to study the effect of fibre orientation on the behaviour of concrete members in compression.

Prismatic specimens (240×100×100 mm) of series FRC-1 and FRC-2 were tested by a displacement controlled Instron type testing machine with the capacity of 500 kN. Rate of cross-head (0.2 mm/min) was chosen so that the displacement controlled test fulfilled the international requirements and standards.

Failure load as well as stress-strain diagram was registered in case of each specimens.

Compressive strength

Test results of compressive tests are numerically summarised in Table 5 and graphically represented in Figure 2 and Figure 3.

Considering results of series FRC-1 and FRC-2 it is obviously that fibre orientation effect the compressive strength of concrete independently from the fibre amount and the concrete type.

Table 5: Concrete compressive strength measured on 240×100×100 mm prism

No.	Notation of mix	Notation of specimen 250×100×100 mm prism						Mean (I, II)	Mean (max)
		C1	C2	C3	C4	C5	C6		
1	FRC-1 ⁷⁵ _{ZP205-I}	39.78	46.19	45.36	45.00	38.97	33.20	41.42	
	FRC-1 ⁷⁵ _{ZP205-II}	36.66	36.38	38.77	44.96	31.04	33.34	36.77	39.10
	FRC-1 ³⁰ _{ZP205-I}	35.99	37.39	30.97	32.91	35.49	.	34.55	
	FRC-1 ¹⁰⁰ _{ZP205-II}	31.23	33.30	32.23	31.08	31.89	34.67	32.40	33.48 36.29
2	FRC-2 ⁷⁵ _{ZP205-I}	37.50	50.03	42.73	47.59	43.84	42.14	44.02	
	FRC-2 ⁷⁵ _{ZP205-II}	40.12	38.60	47.87	48.40	44.75	44.56	44.05	44.04
	FRC-2 ¹⁰⁰ _{ZP205-I}	37.70	38.87	36.68	38.00	39.09	37.29	37.94	
	FRC-2 ¹⁰⁰ _{ZP205-II}	38.00	35.36	32.09	35.68	37.10	.	35.65	36.80 40.42

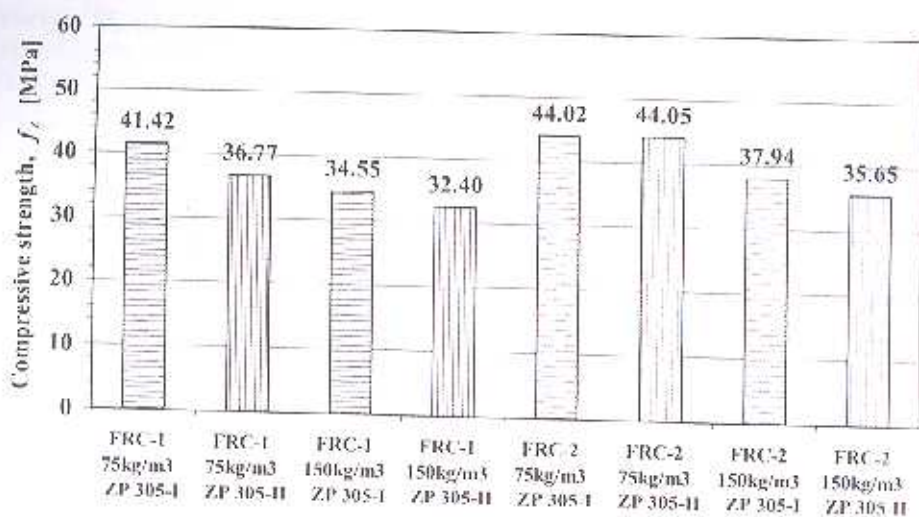


Figure 2: Compressive strength measured on $240 \times 100 \times 100$ mm prisms.
Each column represents the mean volume of 6 specimens.
(Calculated 28 day strength by Weber [12])

In case of concrete mix FRC-1⁷⁵_{ZP 305-II}, concrete strength decreased by 11.2 % related to FRC-1⁷⁵_{ZP 305-I}. When 150 kg/m³ fibre content were applied for mixture FRC-1, reduction in concrete strength was 6.2 % in case of FRC-1¹⁵⁰_{ZP 305-II} related to FRC-1¹⁵⁰_{ZP 305-I}. However, considering concrete mix noted by FRC-2, significant effect of fibre orientation was only detected when 150 kg/m³ steel fibres were applied. Decrease of concrete strength was 6 % for FRC-2¹⁵⁰_{ZP 305-II} related to FRC-2¹⁵⁰_{ZP 305-I}.

As above results indicate, fibres perpendicular to the direction of load more effective to increase compressive strength than fibres which are parallel to the force. Reason of the observed phenomena may lay in the role of fibres in higher tension strength of concrete.

Marked decrease in compressive strength of FRC-1 and FRC-2 made with 150 kg/m³ steel fibres was observed compared with the same concrete composition made with 75 kg/m³ fibre content. This is due to the higher porosity observed in the concrete matrix, concerning larger visible pores appeared on the original concrete and the drilled concrete surface as well.

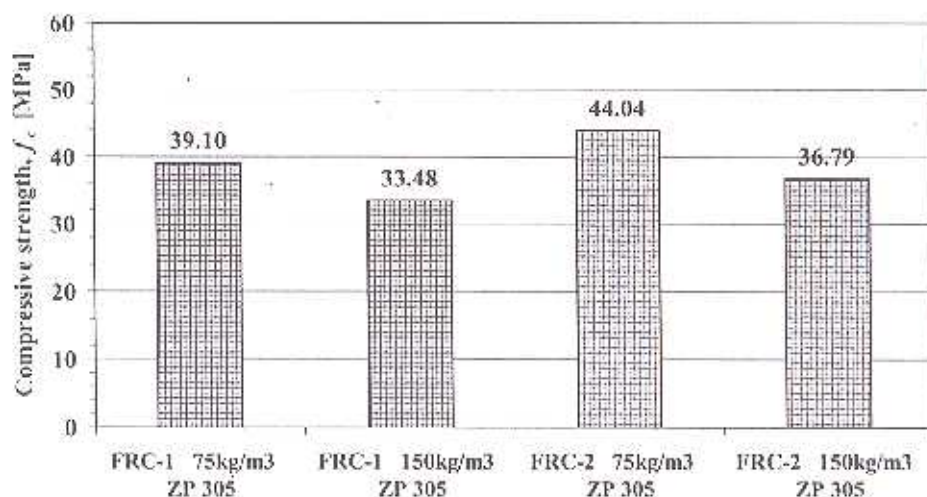


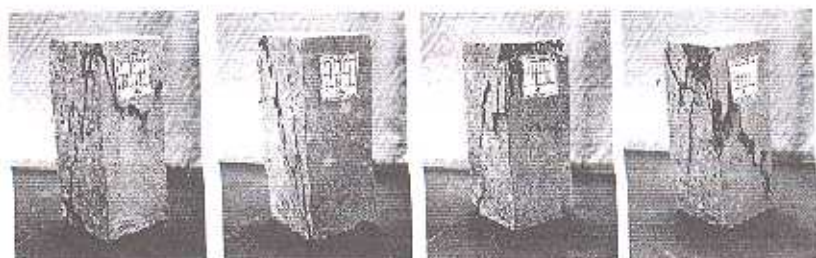
Figure 3: Concrete compressive strength measured on 240×100×100 mm prisms. Each column represents the mean volume of 12 specimens. (Calculated 28 day strength by Weber [12])

Failure of prisms in compression

As results and observations indicate near the failure load, failure mode also significantly effected by the fibre content and the fibre orientation.

Generally, specimens with 150 kg/m³ fibre content indicated tougher failure than specimens with 75 kg/m³ fibre content. Considering a given fibre content, orientation of fibre also effects the failure mode. When the privilege fibre orientation was parallel to the axis of load, more rigid failure was observed. A slightly plastic behaviour was observed after the peak load when the privilege fibre orientation was perpendicular to the axis of load. However, failure mode was very rigid in case of concrete composition FRC-2 independently from the fibre content used.

Diagonal failure was observed as common in case of prismatic specimens independently from the fibre orientation. However, the angel of failure surface was different. When failure was more plastic (privilege fibre orientation is perpendicular to the axis of load), the angel of failure crack was less than that of in case a rigid failure. Typical failure modes are presented in Photo 2.



a)

b)

Photo 2: Failure mode of prisms in compression
 a) very rigid failure with diagonal cracking
 b) considerably plastic failure

TOUGHNESS PROPERTIES

Experimental program and testing procedure

One of the primary objectives of fibre addition to concrete is to improve the energy absorbing capacity of concrete, which can be determined by calculating the area under the stress-strain diagram or the load-deflection relationship [13-16]. In the case of bending, the area under the load-deflection curve is used to estimate the energy-absorbing capacity or toughness of fibre reinforced concrete. Increased toughness means also improved performance in fatigue and impact loading. The toughness mechanism provides ductility. The composite's ability to undergo large deformations before failure is often measured using toughness indexes [13-16].

It is obvious, that contribution of fibres play important role in the toughness properties of fibre reinforced concrete. Major factors that affect the load-deflection performance and hence determination of toughness are the following: fibre type, fibre geometry, fibre volume fraction, concrete composition, geometry of specimen, loading configuration, loading rate, deflection measuring system, type of test control (force or displacement controlled) and the stiffness of testing machine compared to the stiffness of specimen [13-16].

However, measuring of toughness and its expression as well as its design purpose is still under debate [13-16]. When load-deflection curve is

obtained, how to evaluate the factors that contribute to the improved performance is also under debate. Presently available methods for evaluating toughness of steel fibre reinforced concrete on different ways are the following:

- A) *ASTM C 1018 Standard test method of FRC toughness characterisation (ASTM, 1990) [13]*
- B) *JSCE Method of test for flexural strength and flexural toughness of fibre reinforced concrete (JSCE, 1984) [14]*
- C) *Test methods for flexural toughness characterisation of fibre reinforced concrete proposed by Banthia and Trottier (Banthia, Trottier 1995) [15][16]*

These methods are well discussed in the literature. Their basic conceptions are summarised in Figure 4.

Since improved toughness is an important attribute of fibre reinforced concrete these techniques were used to determine toughness of fibre reinforced concrete composition. Experimental parameters, which effected the toughness of fibre reinforced concrete were the fibre content (75 kg/m^3 and 150 kg/m^3), the concrete composition (FRC-1 and FRC-2) and the fibre orientation (I. and II. as discussed before).

For this reason, overall 24 steel fibre reinforced concrete notched beams with the geometry of $85 \times 85 \times 820 \text{ mm}$ were tested in the common four-point bending test over a simply supported span of 765 mm. Hence, shear span to depth ratio was 3. Generally, $100 \times 100 \times 350 \text{ mm}$ or $150 \times 150 \times 600 \text{ mm}$ beams are tested. The developed beam geometry and testing procedure was chosen so that the behaviour of specimen achieves real beam behaviour in bending despite of standard specimens where the shear span to depth ratio is generally around 1.

Beams were drilled out of a concrete slab element as discussed earlier. Notches were formed after drilling of beams at the mid-section of beam with the approximate geometry of $5 \times 5 \text{ mm}$ (5 mm depth and 5 mm width)

The force was applied by a displacement controlled Instron type testing machine with the capacity of 500 kN. Displacements were controlled by two LVDTs placed on both sides of the beams as shown in Figure 5 and in Photo 3. Girder elements of LVDSs were placed by two steel plates glued on both side of the beam at the section of the support. One side of measuring system was performed to be a fix, the other one was a frictional support as shown in Photo 3. The loading rate 0.2 mm/min was chosen according to the ASTM and JSCE recommendations.

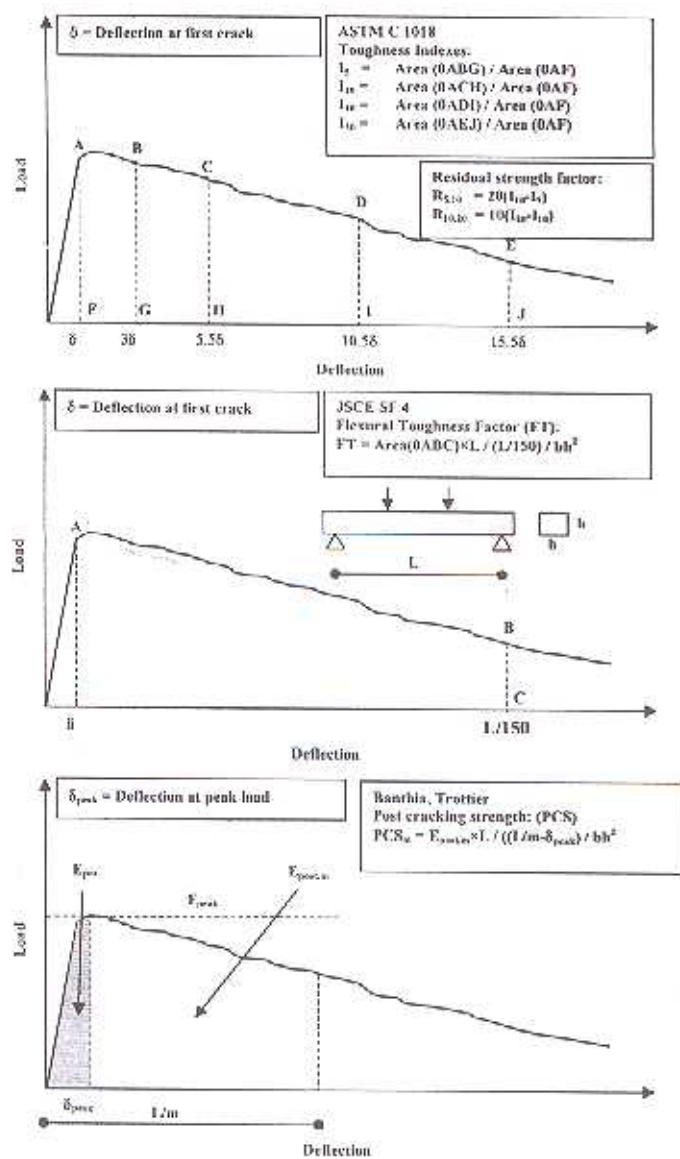


Figure 4: Method for characterizing the toughness properties of steel fibre reinforced concrete

- a) ASTM C 1018 Standard test method of FRC toughness characterization [13]
- b) JSCE SF 4 Method of FRC toughness characterization [14]
- c) Proposal of Banthia and Trotter method of post cracking strength [15][16]

Bending tests and experimental observations

Load vs. deflection relationship

Due to the accuracy of specimens' drilling, geometry of the beams particularly the cross-sections were not exactly the same. For this reason the measured load vs. deflection relationships are not comparable. Therefore, effective bending stress at the mid-section was calculated from the applied load and the geometry of the cross section of beams and hence, bending stress vs. mid-point deflection relationships were developed.

Bending stress vs. mid-point deflection relationships measured in four point bending test for steel fibre reinforced concrete beams are summarised in

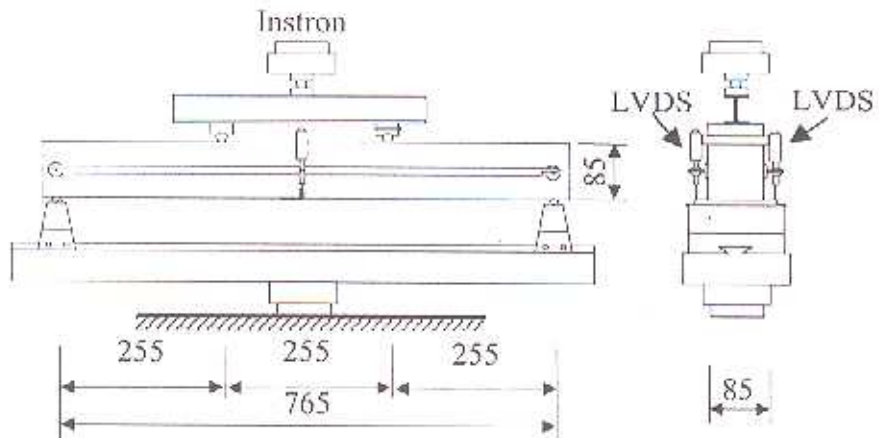
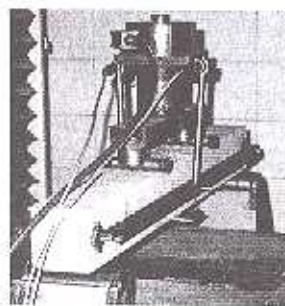


Figure 5: Test set-up and test arrangement



a)



b)

Photo 3: Bending test on steel fibre reinforced concrete beams

a) Test set-up and test arrangement

b) Frictional support of LVDS's girder

Figure 6. First and second columns represents beams in which the privilege fibre orientation is parallel and perpendicular to the axis of the beam, respectively.

All diagrams content three beams noted by Ba, Bb and Bc, which indicate the original position of the beam in the formwork as can be seen in the figures and represented by different colours.

Effect of concrete composition

As diagram indicate significant effect of concrete composition can be found on the bending behaviour of steel fibre reinforced concrete beams. Behaviour of beams made of FRC-2 were more rigid, particularly in case of 75 kg/m^3 fibre content compared to beams made of FRC-1.

Effect of fibre content

Considering the given fibre type, Dramix ZC 305, higher volume fraction provided more energy absorbing capacity or toughness. When 75 kg/m^3 fibre content was applied which is around 1.0 V%, after the first crack the bending stress decreased producing a descending softening branch. Hence, load at first crack was the peak load. Nevertheless, in case of 150 kg/m^3 fibre content the bending stress vs. load deflection relationship suggested a more or less elastic-perfectly plastic material particularly in case of FRC-1. It was a quiet difficult to find the exact position of first crack, since after the elastic branch of the bending behaviour a quasi strain hardening part formed with multiple micro cracking zone.

Effect of fibre orientation

One of the main governing parameter of test series was the fibre orientation. Effect of the privilege fibre orientation on the bending behaviour was found in case of the higher fibre content, 150 kg/m^3 , independently from the concrete compositions. Privilege fibre orientation parallel to the axis of the beam indicated more energy absorption or toughness compared to beams in which the fibres oriented perpendicular to the beam axis.

Effect of beam position

Near the discussed experimental parameters such as concrete composition, fibre content and fibre orientation the original position of beams in the formwork also found to be a parameter of the bending behaviour. Independently from the concrete composition, fibre content and orientation beams noted by "Bc" indicated the less energy absorption or toughness.

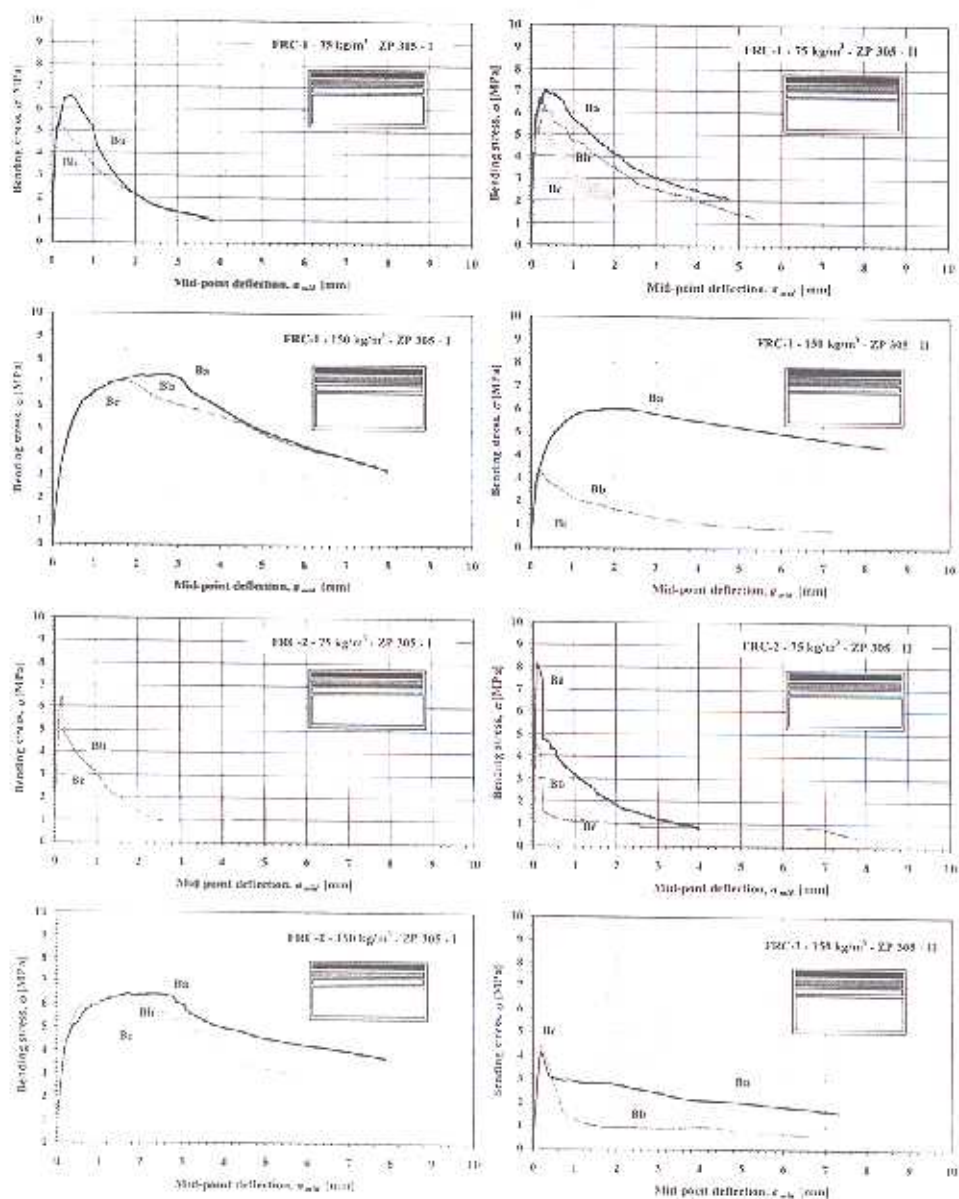


Figure 6: Bending stress – mid-point deflection relationships for steel fibre reinforced concrete beams

Table 6: Toughness properties of steel fibre reinforced concrete according to the ASTM C 1018 and JSCE SF4 (last column)

Concrete mix	Fibre orientation	Beam	Toughness indexes				Residual strength factor		FT
			I_1	I_{10}	I_{20}	I_{30}	$R_{5,10}$	$R_{10,20}$	
FRC-1 ⁷⁵ _{ZP 305}	I.	Ba	4.52	8.65	13.87	16.69	82.62	104.34	-
		Bb	3.89	7.06	11.95	15.42	63.29	97.96	-
		Bc	-	-	-	-	-	-	-
	II.	Ba	4.66	9.55	17.87	24.82	97.80	166.32	-
		Bb	3.74	6.72	11.31	14.41	59.69	91.73	-
		Bc	-	-	-	-	-	-	-
FRC-1 ¹⁵⁰ _{ZP 305}	I.	Ba	3.84	6.42	-	-	51.60	-	3.57
		Bb	3.94	6.95	-	-	60.19	-	3.39
		Bc	4.45	8.81	15.24	-	87.09	64.33	3.24
	II.	Ba	5.14	11.81	26.98	42.66	133.4	151.71	2.36
		Bb	3.66	6.21	10.20	13.22	51.01	39.87	0.72
		Bc	4.71	8.76	13.96	17.33	80.87	52.06	0.42
FRC-2 ⁷⁵ _{ZP 305}	I.	Ba	-	-	-	-	-	-	-
		Bb	2.90	4.73	6.72	-	36.60	39.77	-
		Bc	3.84	6.94	11.77	15.18	62.08	96.58	-
	II.	Ba	4.26	6.98	11.19	14.61	54.40	84.17	-
		Bb	3.57	5.02	6.93	8.70	28.98	38.19	10.92
		Bc	-	-	-	-	-	-	-
FRC-2 ¹⁵⁰ _{ZP 305}	I.	Ba	3.53	5.83	-	-	46.00	-	2.59
		Bb	4.17	8.51	16.10	22.06	86.78	75.89	3.17
		Bc	3.53	6.12	9.88	-	51.82	37.61	2.50
	II.	Ba	3.48	6.25	11.60	16.36	55.46	53.47	1.19
		Bb	-	4.73	6.51	8.15	-	17.83	0.56
		Bc	-	-	-	-	-	-	-

Table 7: Toughness properties of steel fibre reinforced concrete (PCS) according to Banthia and Trottier

Concrete mix	Fibre Orientation	Beam	Post Cracking Strength, PCS								
			3000	1500	1000	750	600	400	300	200	150
FRC-1	I.	Ba	-	-	-	-	-	-	-	-	-
		Bb	4.63	3.77	3.51	3.26	3.03	2.51	2.09	-	-
		Bc	-	4.20	3.94	3.82	3.64	3.24	2.91	2.39	-
	II.	Ba	12.19	9.64	8.32	7.60	7.04	5.96	5.13	4.04	-
		Bb	3.14	1.99	1.64	1.43	1.33	1.17	1.09	-	-
		Bc	-	-	-	-	-	-	-	-	-
FRC-1	I.	Ba	-	-	-	-	-	-	4.24	4.02	3.64
		Bb	-	-	-	-	-	-	3.94	3.67	3.45
		Bc	-	-	-	-	-	3.95	3.85	3.57	3.28
	II.	Ba	-	-	-	-	-	2.60	5.98	4.32	-
		Bb	1.49	1.34	1.27	1.20	1.13	1.02	0.93	0.81	0.72
		Bc	-	-	0.72	0.72	0.71	0.62	0.56	0.47	0.40
FRC-2	I.	Ba	-	22.70	20.75	19.7	18.0	14.3	12.0	9.12	-
		Bb	-	4.74	4.30	4.01	3.76	3.53	3.03	2.66	-
		Bc	-	-	-	-	-	-	-	-	-
	II.	Ba	-	21.65	19.62	18.5	17.8	16.0	14.6	12.3	10.6
		Bb	-	5.87	5.76	5.48	5.29	4.75	4.31	3.63	-
		Bc	-	-	-	-	-	-	-	-	-
FRC-2	I.	Ba	-	-	-	-	-	3.29	3.20	2.89	2.35
		Bb	-	-	-	-	-	-	3.78	3.41	3.13
		Bc	-	-	3.27	3.31	3.35	3.18	3.05	2.78	2.55
	II.	Ba	1.87	1.53	1.44	1.40	1.37	1.34	1.30	1.21	1.14
		Bb	-	-	1.32	1.09	0.95	0.76	0.67	0.58	0.53
		Bc	-	-	-	-	-	-	-	-	-

Toughness properties

However, based on the load vs. mid-point deflection relationships different toughness properties were calculated as summarised in Figure 4. Toughness indexes (ASTM), toughness factors (JSCE) and post cracking strength volumes (Banthia, Trottier) summarised in Table 6 and Table 7.

Obviously, larger fibre amount led larger toughness indexes since more fibre crossing the crack surface more tension force transferred.

As result indicate, when the privilege fibre orientation is perpendicular to the cross-section of beam, in case of mixture I. - more fibres crossing the

cracked surface - larger toughness index can be calculated independently from the other experimental parameters.

Concrete compositions also effected the toughness properties. Considering beams made of concrete mix FRC-1 proceed larger toughness than beams made of mixture FRC-2.

However, toughness index is significantly effected by the beam position in formwork at casting. Better toughness properties and bending behaviour was observed in case of beam noted by "a".

Unfortunately, there was no comparable result concerning the flexural toughness determined according to JSCE. However, FT numbers also suggest, that the position of beam in the formwork is an important experimental parameter.

Similarly to the common method determining the toughness parameters, the new proposal of Bathia and Trottier indicate that higher fibre content yield to higher post cracking strength.

CONCLUSIONS

An intensive experimental study was developed at Budapest University of Technology and Economics to determine the mechanical and toughness properties of steel fibre reinforced concrete.

Experimental parameters were:

- Concrete composition: FRC-1, FRC-2
- Fibre content: 75 kg/m³, 150 kg/m³
- Principle fibre orientation: I. and II.
- Position of specimens in the formworks

Experimental constants were:

- Geometry of specimens: prisms (240×100×100 mm)
beams (820×85×85 mm)
- Type of fibre: Dramix[®] ZP 305
- Testing machine: INSTRON (500 kN capacity)

Based on the experimental results and observations the following conclusions can be drawn:

- 1) Steel fibre reinforcement effects the concrete compressive strength. Higher fibre dosages (150 kg/m³) may result in decrease in compressive strength of concrete.
- 2) Fibre orientation effects not only the failure mode but slightly the compressive strength as well.

- 3) Fibre content significantly improves the energy adsorption and toughness of concrete. The more fibre, the more ductile behaviour can be found.
- 4) Fibre orientation has an expressive effect on the bending behaviour and toughness properties of steel fibre reinforced concrete. When the principal fibre orientation is perpendicular to the cross-section, higher toughness index can be obtained.
- 5) At relatively high fibre dosages (150 kg/m^3) multiplied cracking zones took place resulting a quasi strain hardening behaviour in bending. Cracking load can not be estimated exactly.
- 6) Considering a quasi strain hardening behaviour, the strain measured at peak load is generally much higher than in case of normal reinforced concrete. Therefore, the existing methods determining the toughness indexes are not suitable.

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Szálorientáció hatása a beton szivósságára

A dolgozatban kísérleti programot és annak eredményeit mutattunk be, melynek célja acélszálerősítésű betonok mechanikai tulajdonságainak meghatározása, ill. szivósságának jellemzése volt. Kísérleti paraméter volt a betonok összetétele, száltartalma, és a szálak orientációja. Kísérleti állandó volt a próbatestek geometriája, az alkalmazott száltípus valamint a kísérleti berendezés ill. elrendezés. A kísérletben beton nyomószilárdságot határoztunk meg $240 \times 100 \times 100$ mm méretű hasábokon valamint harmadpontos terhelésnek vetettünk alá $820 \times 85 \times 85$ mm méretű acélszálerősítésű betongerendákat. A hasábok nyomószilárdságát és törési mechanizmusát vizsgáltuk a szálorientáció függvényében valamint acélszálerősítésű betongerendák terhelőerő középponti lehajlás függvényeit rögzítettünk különböző szivóssági indexek meghatározásához.

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COLLEGE LEVEL TRAINING IN ELECTRICAL ENGINEERING BASED ON UNIVERSITY EDUCATION IN PHYSICS AND ELECTRONICS AT DEBRECEN UNIVERSITY

Due to the need of rapid exploitation of the results of materials-, information- and bio-technology and the correspondingly good job opportunities for graduates the engineering studies attract currently higher attention worldwide, so in Hungary as well. The college level and university level of training in technology were traditionally separated in Hungary. The transition to the two-stage training in higher education, i.e. training for the BS and MS degrees, has to be founded actually. For the Debrecen University the specific challenge lies in the adaptation of the science courses, developed for the training of physicists for the requirements of the training in college level engineering providing the bachelor level. The experience of the first two years and future possibilities are discussed in this paper.

1. INTRODUCTION

Over the last few years the recruiting of capable, interested students for natural science studies is a general concern of physics departments almost all over the world. Studies in natural sciences belong to the "elite education", as degrees in natural science are the prerequisite for the carrier in scientific research. At the same time training of higher-level specialists for jobs closer to the practice is an increasing economic requirement of the developing societies. Due to the exploitation need of the results of an extremely rapid development of materials-, information- and biotechnology and due to the correspondingly good job opportunities for graduates the engineering studies attract currently higher attention?

For the regional technical development it is paramount to have locally sufficient number of specialists available. In the region Eastern Hungary this is tightly connected to electronics. This was the main reason for initiating the college-level specialization in electrical engineering at the University of Debrecen some