FIBER CONCRETE FOR CONSTRUCTION MEMBER SUBJECTED TO BENDING LOAD

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Abstract. In present work possibility to obtain high performance steel fiber reinforced concrete (showing high mechanical tensile strength and stiffness properties) is under investigation. Different types of commercially available fibers (having different geometry) were observed. After numerous experiments, were executed, the mix design basic principles for fiberconcrete with high content of fibers were elaborated.

More than 50 fiberconcrete mixes were investigated and comprehensively analyzed with the goal to find material with simultaneously optimal rheological and strength behavior. The experiments resulted in acquisition of close to self-compacting concrete for mix with fiber content over 300 kg/m^3. Bending tests were performed for 10x10x40cm and 15x15x60cm prisms and stress - strain diagrams (measuring applied load, deflection and crack mouth opening displacement) for fiber reinforced concrete were obtained. Investigation results are opening possibility to use this material in constructions subjected to bending forces without traditional reinforcement.

Keywords: fibre concrete, steel fibre, workability, grading curve, flexure, strength

1. Introduction
Fibre Concrete as Construction Material

Adding fibers to concrete we can expect additional benefits and safety improvements: increase stiffness, flexural and tensile strength, impact resistance, as well as post-cracking stiffness.

Commercially available fibers made of different materials are: steel, glass, carbon, aramid, polypropylene, polyethylene and (with smaller application) some others. Important is fiber material mechanical compatibility with concrete matrix. Non-metallic fibers, traditionally, have lower stiffness (longitudinal Young modulus) comparing with steel and their work in concrete leads to high micro-cracks concentration accumulation in concrete matrix during fibers loading (for example polypropylene have about 20 times less Young modulus then steel), important are thermal expansions and chemical compatibilities (for fiber material – concrete matrix). Some materials are relatively expensive (for example carbon fibers).

Summarizing above mentioned is possible to say: at present time Steel Fibre Reinforced Concrete **(SFRC)** is more commercially attractive material with replaced (fully or partially) traditional steel reinforcement find the wide range of applications in construction industry, as load bearing material.

Two main directions of steel fibre application in concrete may be recognized:

1) Modify conventional concrete constructions with traditional reinforcement. Steel fibre content in this case usually is **20 kg/m^3 - 80 kg/m^3**.

2) To replace traditional reinforcement and use fiber concrete for construction members.

In this case positive result may be achieved when steel fibre content is **> 80 kg/m^3 - 100 kg/m^3**.

First attempts to use short steel fibers as concrete disperse reinforcement was dated by the beginning of previous century [1 - 5]. Question is why this reinforcement not so popular like steel bars and cage? As the answer can be mention set of problems which restrict SFRC wide application as constructional material:

a) material is highly heterogeneous. Without additional chemical admixture not possible to mix and pump concrete with fiber content higher than 20 kg/m^3-30 kg/m^3;
b) material has higher price comparing with conventional concrete;
c) important is fibre orientation, exists technological problems in mixing, pumping and compaction. Constructive SFRC is not only plane concrete with fibers, various fiber combination, its content as well as concrete aggregate composition can be used;
d) each type of SFRC has specific properties and field of application. At present, variety of SFRC investigation methods are used therefore

unified international test method and construction design procedures still not are adopted.

Important is concrete with relatively high fiber content. One of the main problems for concrete mixes with high fibre content is loss of workability (concrete mix become stiff and non-workable). Use of effective chemical admixtures and application of modern concrete mix design methods nowadays are helping to solve this problem. The aim of this investigation is to obtain concrete mix with good workability, which may be applied in standard ready-mix concrete plant.

Nowadays many practical examples of FRC use as constructive material can be found. For example, 6 x 6 m floor slabs in trade store in Daugavpils, Latvia (Fig. 1), floor slabs for Kolde Tee in Tallinn, Estonia and others. Small grain SFRC concrete is widely used as shotcrete material in tunnel constructions [5].

Fig.1. Floor concreting in Daugavpils, Latvia.

2. Mix design for SFRC

Generally, SFRC mix design method is based on conventional concrete mix design theory. The main common principles are: Low water/cement ratio; aggregate packing based on "ideal" grading curves; water content determination on the principle of absolute volumes [6].

Specific in SFRC mix design is the following:

- Fibers can be observed as aggregate with determined specific surface and very unfavourable shape, what requires more paste content to provide normal workability. It may be achieved by correction of aggregate "ideal curve" to provide good workability.
- It is important to provide good contact zone between fibers and cement paste, so water/cement ratio must be as low as possible.
- To achieve good workability and strength characteristics, superplasticizer and mineral micro fillers must be used.
- Aggregate maximum size must be not larger then the size of fibre.

3. Mix ingredients

Multi-component aggregate mix was used with the aid to provide optimal particle packing and good mix workability. Natural local fine and course sand, as well as gravel 2-8 mm was used. Dolomite powder and microsilica was applied as micro fillers. Third generation superplasticizer was used to provide mix fluid consistency and minimize water/cement ratio.

Commonly used parameter to characterize the fibre is length to diameter ratio (L/D). Increasing L/D ratio is growing fibre effect on the material's tensile strength and simultaneously is dropping down mix workability. Practically fibers with L/D ratio 50-80 are used.

To provide better fibre contact with concrete, special fibre's surface treatment and shape geometry are used (hooked ends, undulated, etc.). It must be pointed, that fibre content (kg/m^3) is not the main factor for SFRC strength, because the number of fibers in 1 kg can vary considerably depending on the size of them. Used fibre types and their characteristics are summarized in Table1.

Table 1

Used fibres

Fibre Type	Description	Length, mm	Diam., mm	L/D ratio	Number in 1 kg
Wiremix W50	flat, ondulated	50			2040
Tabix 1.0/60	rounded, undulated	60	1	60	2500
Tabix 1.3/50	rounded, undulated	50	1.3	38	1800
Tabix 1.0/50	rounded, undulated	50	1	50	3100
Dramix 80/60	rounded	60	0.75	80	4700
Dramix ZP 305	rounded	30	0.54	56	16500
Dramix 80/30	rounded, brass coated	30	0.375	80	35000
Dramix OL 13/16	rounded, brass coated	13	0.16	81	500000
Dramix OL 6/0.16 HC	rounded, brass coated	6	0.16	38	1120000

4. Testing methods

Raw materials was weighed and mixed in laboratory drum mixer. Beams with the size 15x15x60 cm were casted in steel moulds. After 30-35 days of curing in moisture condition (RH > 95%, 20±2°C) samples was tested under 4-point bending in accordance with RILEM recommendation [7]. Notching (1/10 from the highs of cross section) was made to control the crack's place and opening. The scheme of experiment is shown at Fig. 2. Highly precise deflection and pressure sensors were used. All signals were summarized using data acquisition system connected to computer. Load – Deflection and Load – Crack Mouth Opening Displacement (CMOD) was simultaneously measured (see Fig.2.). The maximal stress, as well as stress corresponding crack opening 0.5 and 3.5 mm ($\sigma_{0.5}$ and $\sigma_{3.5}$) was measures as characteristic parameters of material.

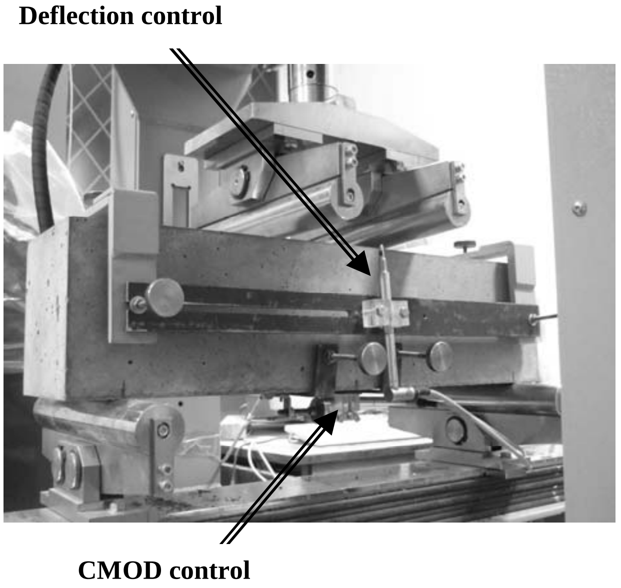

Fig. 2. Sample testing

5. Mix compositions and experimental results

For SFRC mix compositions, aggregate grading curves were taking into account. Optimal aggregate grading can be approximated using modified Fullers low for ideal grading curve [8]:

$$YT(I)=(100/(1-(X_o/X_{max})^n)\cdot((X(I)/X_{max})^n-(X_o/X_{max})^n) \quad (1)$$

where: YT(I) is sieve passing value;

X_o is the ideal curve starting point;

X_{max} is the ideal curve finishing point;

n is the power degree;

X_o = 8 mm; X_{max} and n are the variables.

Experiments with different SFRC mixes shown, that conventional concrete mixes may be used only with fibre content below 100-120 kg/m^3 (type 1 curve in Fig. 3). Fibre content more than 100 kg considerably decreases mix workability. To provide mix workability and pumpability with high fibre content, small aggregate fraction content must be increased. Modified grading curve for SFRC, with high bending strength, are similar to Self Compacting Concrete [9] grading curves (type II and type III curves in Fig.3).

More than 50 fiberconcrete mixes were elaborated in RTU Concrete Mechanics laboratory and comprehensively investigated with the goal to find material with simultaneously optimal rheological and strength behaviour. Samples of typical mix compositions and its properties are summarized in table 2.

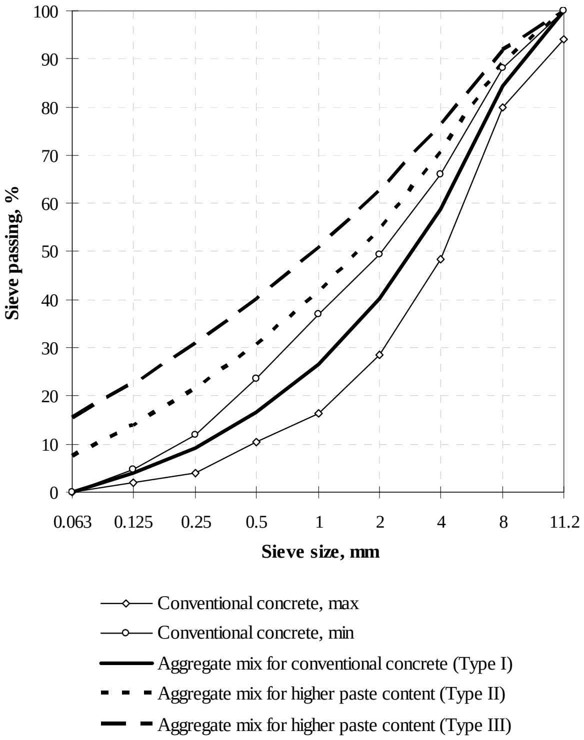

Fig. 3. Aggregate grading curves for SFRC

Table 2

SFRC mix compositions

	Type I aggregate grading		Type II aggregate grading	Type III aggregate grading
Cement CEM II A-V 42.5 N	380	380	470	680
TABIX 1.0/50	-	150	70	168
DRAMIX 80/30	-	-	65	56
Dramix OL 13/16	-	-	-	28
DRAMIX OL 6/0.16 HC	-	-	60	9
Fibre total:	-	-	195	262
Fibre % by volume	0	1.9	2.5	3.4
Cone slump, cm	22.5	8.5	22	15
σ_{max}, MPa	**6.0**	**9.9**	**16.2**	**22.5**
CMOD (Fmax), mm	-	-	1.95	1.14
$\sigma_{0.5}$, MPa	-	-	14.0	19.9
$\sigma_{3.5}$, MPa	-	-	15.2	19.5

Influence of fibre content on bending strength and mix cone slump of SFRC are shown in Fig. 4 (for the case of conventional concrete Type 1).

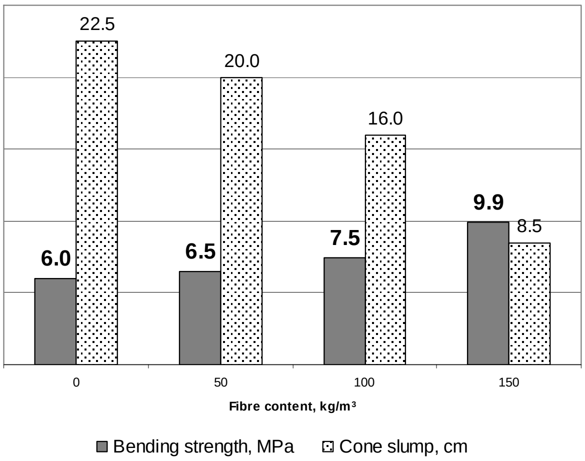

Fig. 4. Influence of fibre content on flexural strength and mix cone slump for SFRC

The next stage of research was to find optimal proportion for different fibres types (in the case of "fibercocktail" use) and appropriate aggregate grading curves, that provides high stress - strain characteristics and simultaneously ensure homogenous and pumpable concrete mix with cone slump > 150 mm.

Obtained stress - deformation diagrams are shown in Fig. 5.

It is possible to mention, that fibre pulling-out from cement matrix was the main mechanism for all tested samples (example in Fig. 6).

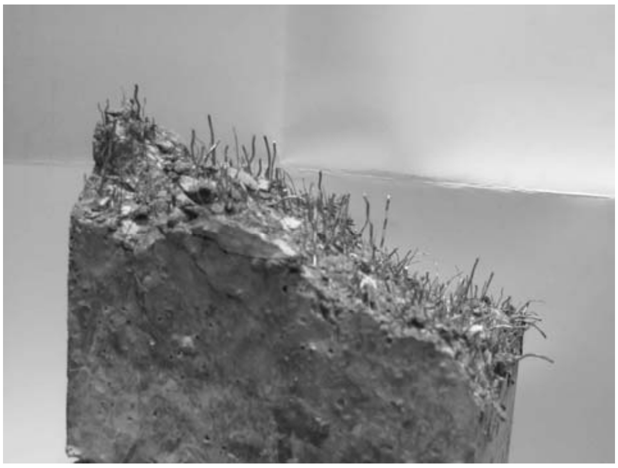

Fig. 6. SFRC sample after destruction

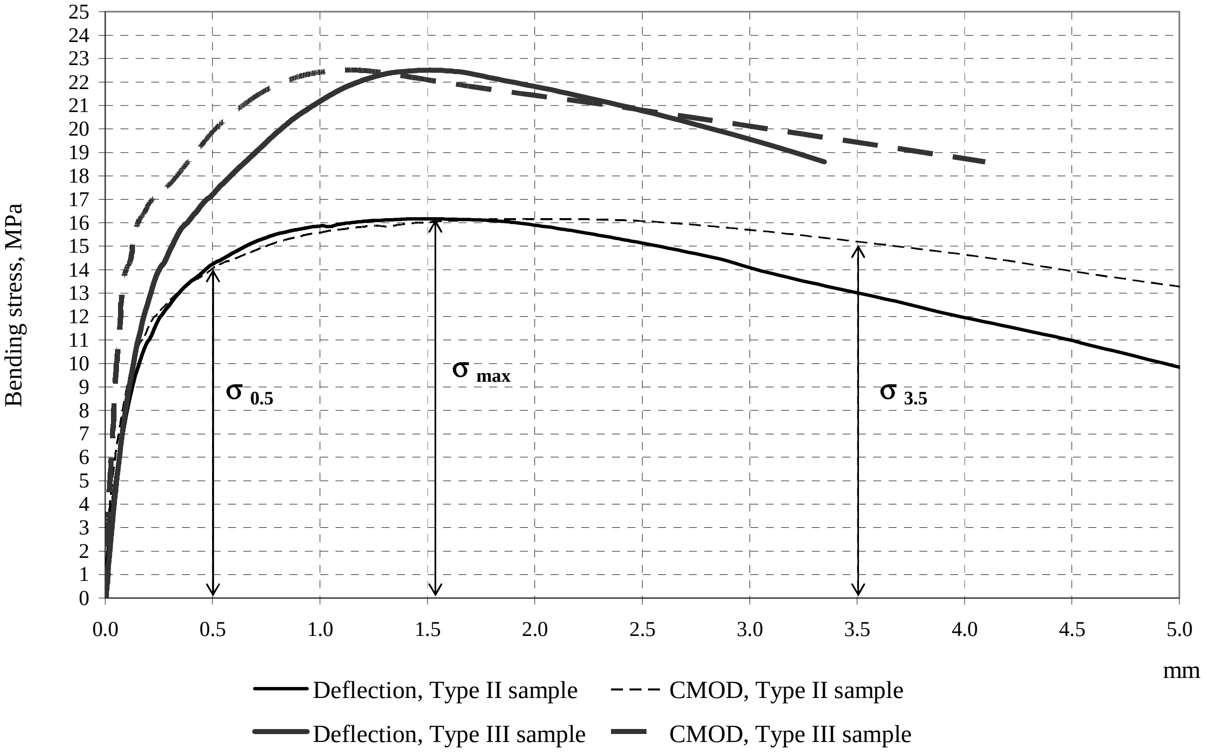

Fig. 5. Stress - deformation diagrams

6. Conclusions

Adding steel fibres reduce workability of concrete mix. Satisfactory workability of conventional concrete (having traditional content of cement and paste) was obtained with fibre concentration below 100 kg/m^3. Higher fiber content requires a new approach to mix design: higher paste content and grading curve close to self compacting concrete curve.

Use of multisided fibre composition ("fibre cocktail") with increased paste content allow to achieve high flexural strength (>20 MPa) in the same time provided good mix workability, close to self compacting concrete. Each fibre size play the defined role in concrete: long fibres bridging the cracks, small fibres constrain concrete matrix around larger fibres increasing pull-out force for the last.

SFRC aggregate grading curve must be selected in dependence on required mechanical behaviour and consistency of concrete mix in accordance on material application.

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