BRANDED FIBRECONCRETE
FROM DEVELOPMENT TO PRACTICAL USAGE

V. Veselý[1], A. Kohoutková[2], J. Vodička[3], S. Smiřinský[4], J. Krátký[5], J. Vašková[6]

Abstract

As a specific construction material, fibre-concrete has been tested and used in the world for several decades. The tradition of its research, development and usage has been quite long also in the Czech Republic. Practical usage of fibre-concrete in constructions or prefabricated elements is still complicated due to a large spectrum of non-uniform testing methods that are both standardized and non-standardized. These facts also result in different approaches to static calculations. This article shows a specific application of fibre-concrete with scattered steel fibres, i.e. steel- fibre concrete. The article describes the procedure that resulted in the final product – the very first designed steel-fibre concrete that was used for testing and classification; preparation of a company standard and finally branded types of fibre-concrete that are offered for sale, i.e. STEELCRETE and FLOORCRETE.

Key words: fibre-concrete, development, standard, branded product, STEELCRETE, FLOORCRETE

1. Introduction

As a relatively new material fibre-concrete has often to overcome conservative approach of designers and building companies, especially as far as its usage in supporting structures is concerned. Many people prefer to choose well-proven materials and technologies because a unified system of standards for their testing and composition has existed for a long time and the quality of materials and technologies have been proven by long-term usage. Fibre-concrete has been known, tested and used for several decades, however, it is partially

1 Vladimír Veselý, BETOTECH, s.r.o, Beroun 660, 266 01 Beroun, vladimir.vesely@cmcem.cz

2 Alena Kohoutková, CTU in Prague, Faculty of Civil Engineering, Thákurova 7, 16629 Prague 6 alena.kohoutkova@fsv.cvut.cz

3 Jan Vodička, CTU in Prague, Faculty of Civil Engineering, Thákurova 7, 16629 Prague 6, jan.vodicka@fsv.cvut.cz

4 Stanislav Smiřinský, BETOTECH, s.r.o, Beroun 660, 266 01 Beroun, stanislav.smirinsky@betotech.cz

5 Jiří Krátký, CTU in Prague, Faculty of Civil Engineering, Thákurova 7, 16629 Prague 6, jiri.kratky@fsv.cvut.cz

6 Jitka Vašková, CTU in Prague, Faculty of Civil Engineering, Thákurova 7, 16629 Prague 6, jitka.vaskova@fsv.cvut.cz

handicapped by the non-existence of a unified system of standards. Different states have different guidelines and technological recommendations, but yet no universal standard has been adopted within a group of countries, e.g. within the EU. Such a standard has been under preparation.

2. Design

One possibility how to increase general awareness of fibre-concrete is to show how it can be used. Here we describe a procedure of a branded-product development.

2.1 Intention

The intention of the project was to introduce an already existing product, i.e. steel-fibre concrete with predefined qualities and properties. The aim was to increase general awareness of designers, construction companies and investors so that they would use this material more often in future. Concrete reinforced with steel fibres was chosen deliberately because this type is best known among people at the building market.

2.2 Solution

The present situation of the Czech building industry had to be considered. So far, laboratories, research centres and universities have been using different procedures for testing steel-fibre concrete. Guidelines and standards from abroad have been used as well (e.g. from Germany [1] and [2], Austria [3] and Great Britain [4]). No Czech procedures or guidelines for designing engineering constructions existed, except for the foreign ones mentioned above. In the Czech Republic we had only a guideline draft which was published in the bulletin "Steel fibre-concrete constructions" [5].

The project was divided into the following phases:

- elaboration of technological conditions for fibre-concrete
- elaboration of a product-standard
- standardization of technological guidelines in the form of a constructional-technological certificate
- branded products design
- preparation of recipes; testing properties according to the standard
- final design for the building market

deliveries of branded products

2.3 Research team

The team consisted of people who already participated in similar projects. The initiator was Ceskomoravsky beton a.s., a company that has been operating a net of RMC plants all over the Czech Republic. These plants have been providing not only ready-mixed concrete but also transport and pumping services. The know-how came from the Department of Concrete and Masonry Structures, Faculty of Civil Engineering, Czech Technical University in Prague. Members of this department have had long experience in research, testing and practical usage of fibre-concrete. The department has also developed an evaluating system for test results, which converts them into variables that are used in designing engineering constructions.

The practical part was realized by the company BETOTECH s.r.o. It involved elaboration of new recipes, testing fresh and hardened steel-fibre concrete, classification of steel-fibre concrete and issuing initial tests.

3. Phases of the project and their results

3.1 Technological conditions and elaboration of a product standard

At first, technological conditions TP FC 1-1 [6] were elaborated; they involved: definitions, testing procedures, evaluation of performed tests, evaluation of fibre-concrete strength and ductility characteristics. In addition to standard tests, which are analogous to those of plain concrete, the four-point flexural test was chosen as a decisive test to specify ductility characteristics (Fig. 1).

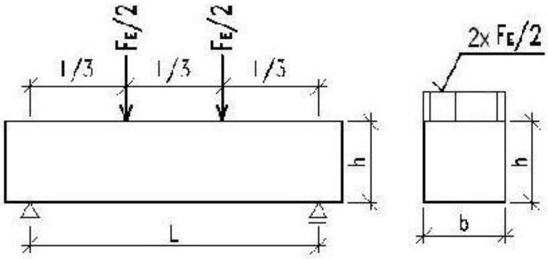

Fig.1: Flexural strength test on a recommended standardized prism (h=b=150mm, L=600mm)

Speed of load increase was tested by two selected procedures:

When monitoring non-linear behaviour of fibre-concrete, the procedure is divided into three phases; speed of load increase is different in each phase

<u>1st phase</u> - v_{f1} = 0,01 mm/min in the interval of Δt_1 = 20 min, i.e. till the deflection is $\Delta\delta_1$ = 0,2 mm, for stabilization of the tested prism in the testing equipment,

<u>2nd phase</u> - v_{f2} = 0,2 mm/min in the interval of Δt_2 = 30 min, i.e. till the deflection increase is $\Delta\delta_2$ = 6,0mm or till the total deflection is δt_2 = 6,2 mm; for this deflection the basic resistance diagram is usually designed; $F_R - \delta_t$ of the standardized prism (for $F_R = F_E$),

<u>3rd phase</u> - v_{t3} = 0,5 mm/min in the interval of Δt_3 = 20 min, i.e. till the deflection increase is $\Delta\delta_3$ = 10 mm of till the total deflection is δt_3 = 16,2 mm, on condition that the load test continues on a standardized prism by a flexure test.

If monitoring of non-linear behaviour of fibre-concrete is not required or if at least 6 prisms are at disposal, the testing time can be shortened by using just one testing phase with a uniform speed of load increase v_f = 0,2 ± 0,05 mm/min, at least until the deflection increase is $\Delta\delta$ = 4,0 mm; it means that the average testing time for one prism is ca 20 min.

Results of the test are then converted into characteristics of fibre-concrete ductility that result in classification of fibre-concrete in particular classes according to tensile strength before a macro-crack appeared (Charter 1) and after a macro-crack appeared (Charter 2); these ductility characteristics are independent of characteristic compressive strength.

Charter 1 Fibre-concrete - tensile strength classes on the micro-cracking point

Strength class – concentric traction 1) 2) $f_{fc,tk}$ [MPa]	Characteristic tensile flexural strength $f_{fc,tk,fl}$ [MPa]	Characteristic strength in transverse traction 3) $f_{fc,tk,sp}$ [MPa]
0,9	1,3	1,1
1,1	1,6	1,3
1,3	1,9	1,5
1,5	2,2	1,8
1,8	2,6	2,1
2,0	2,9	2,4
2,2	3,2	2,6
2,5	3,6	2,9
2,7	3,9	3,2
2,9	4,2	3,4
3,0	4,4	3,5
etc.	etc.	etc.

Charter 2 Fibre-concrete – strength classes – residual traction after macro-crack appearance

Fibre-concrete – strength classes – residual concentric traction $f_{fc,tk,res,j}$ [MPa]				
0,4	2,0	3,6	5,2	6,8
0,6	2,2	3,8	5,4	7,0
0,8	2,4	4,0	5,6	7,2
1,0	2,6	4,2	5,8	7,4
1,2	2,8	4,4	6,0	7,6
1,4	3,0	4,6	6,2	7,8
1,6	3,2	4,8	6,4	8,0
1,8	3,4	5,0	6,6	etc.

The obtained parameters resulted in the final specification of the product that is formulated by strength characteristics. Technological conditions allow two methods:

- fibre-concrete – strength classes

$$FC\ f_{fc,ck} / f_{fc,ck,cub}\ -\ f_{fc,tk} / f_{fc,tk.res,j}\ -\ f_{fc,tk.sp}$$

- fibre-concrete – strength classes and ductility characteristics

$$FC\ (f_{fc,ck} / \varepsilon_{fc,cu}) / f_{fc,ck,cub}\ -\ f_{fc,tk} / (f_{fc,tk.res,j} / \varepsilon_{fc,t,res,j})\ f_{fc,tk.sp}$$

Where:

$f_{fc,ck}$ – is the characteristic (cylindric) compressive strength of fibre-concrete

$f_{fc,ck,cub}$ – is the characteristic (cube) compressive strength of fibre-concrete

$f_{fc,tk}$ – is the characteristic concentric tensile strength of fibre-concrete

$f_{fc,\ tk,res,j}$ – is the residual strength in characteristic concentric traction at agreed deflection δ_{tj} of fibre-concrete

$f_{fc,tk,sp}$ – is the characteristic strength in transverse traction of fibre-concrete

$\varepsilon_{fc,cu}$ – is the critical relative compression of fibre-concrete

$\varepsilon_{fc,t,res,j1}$ – is the relative extension in concentric traction at $f_{fc,tk,res,j}$ of fibre-concrete

3.2 Product standard, constructional-technological certificate

Following TP FC 1-1 [6] (see Fig. 2) a company product standard was elaborated (PN CMB 01-2008 [7] – see Fig. 3). This product standard is based on the valid one for plain light and heavy concrete (CSN EN 206-1, Concrete, specification, properties, production and conformity control. Terms concerning fibre-concrete are defined in this product standard, especially:

Designed fibre-concrete: concrete for which (in accordance with the standard CSN EN 206-01) the required properties and additional characteristics are specified to the producer who is responsible for providing concrete conforming to the required properties and additional characteristics.

Fibre-concrete with guaranteed volume of fibres: concrete of the basic structure (according to the standard CSN EN 206-01) into which a guaranteed volume of fibres is added; the fibres of guaranteed volume might be of any material, shape and size.

The company standard also comprises further requirements on fibre-concrete:

- Classification
- Requirements concerning material composition of fibre-concrete, incl. requirements on fibres
- Methods of properties verification (testing methods)
- Specification, deliveries, conformity control, production control, classification

Product standardization was finished by issuing a constructional-technological certificate STO 060-028542 [8], see Fig. 4.


Prosinec 2007

ČESKOMORAVSKÝ BETON

Technické podmínky 1: Vláknobeton – Část 1 Zkoušení vláknobetonu – Vyhodnocení destruktivních zkoušek a stanovení charakteristického pracovního diagramu vláknobetonu pro navrhování vláknobetonových konstrukcí

TP FC 1-1

Fig. 2: TP FC 1-1


PN ČMB 01-2008

Technická norma

Červen 2008

ČESKOMORAVSKÝ BETON

PN ČMB 01-2008

Vláknobeton (FC) - Specifikace, vlastnosti, výroba a shoda

Tato technická norma je vydána jako navazující technická norma na normu ČSN EN 206-1 a upravuje a doplňuje požadavky na vláknobeton - beton obsahující rozptýlená vlákna.

Tato technická norma je výhradním duševním vlastnictvím společnosti Českomoravský beton, a.s.

Fig. 3: PN ČMB 01 - 2008


ZÚS

TECHNICKÝ A ZKUŠEBNÍ ÚSTAV STAVEBNÍ PRAHA, s.p.

Technical and Test Institute for Construction Prague

Autorizovaná osoba 204 podle rozhodnutí ÚNMZ č. 29/2006

Pobočka 0600 – Brno

vydává

STAVEBNÍ TECHNICKÉ OSVĚDČENÍ

č. 060-028542

výrobek:

Beton pevnostních tříd C12/15 (B 15) a vyšší

pro konstrukce pozemních, inženýrských a dopravních staveb

typ / varianta: **vláknobeton**

žadatel:

ČESKOMORAVSKÝ BETON, a.s.

Fig. 4: STO 060-028542

3.3 Branded products designing

The two basic types of steel fibre-concrete were given names in accordance with the company standard of the producer (Ceskomoravsky beton) to facilitate communication with designers, building companies and investors.

STEELCRETE – is a branded designed type of concrete with steel fibres (see 3.2). The producer guarantees its predefined characteristics, incl. the ductility. Designers can choose a particular type of STEELCRETE from the basic offer or can ask for individual characteristics that a particular construction requires. In such a case the producer ensures and guarantees production of fibre-concrete with the required characteristics.

STEELCRETE is intended for constructions made of plain fibre-concrete or of fibre-concrete combined with reinforcing elements incl. tendons. STEELCRETE is recommended mainly for bed-slabs and underground walls (e.g. so-called waterproof white tanks). In general, STEELCRETE can be used for all supporting structures.

FLOORCRETE – is a branded type of fibre-concrete with guaranteed volume of steel fibres. The producer guarantees properties of common concrete and the type and volume of fibres. The customer provides parameters required for a particular industrial floor (bearing capacity of the subgrade, load caused by vehicles, constant load). The producer orders statistic calculation of the slab at the steel fibres supplier. The supplier also recommends which type of concrete should be used, type and volume of steel-fibres in a volume unit. The producer delivers FLOORCRETE incl. steel-fibres, guarantees and checks concrete properties, volume of steel fibres in a volume unite and homogeneity of the mixture. FLOORCETE is recommended especially for industrial floors.

3.4 Recipes, taking tests of parameters according to the standard

When designing recipes, the basic target was to prepare constructional fibre-concrete with given and guaranteed characteristics. It was necessary to observe principles and requirements concerning fresh concrete properties (homogeneity, workability, pumpability) and hard concrete properties (strength characteristics incl. ductility). Also steel fibres properties had to be considered. Out of a wide spectrum of steel fibres (with different lengths, shapes, tensile strengths) one type was chosen (length: 50 mm; cross-section: 0,75 mm; tensile strength 1100 MPa). This type is commonly used in concrete for industrial floors. The aim was to design fibre concrete with compressive strength that corresponds with commonly used concrete C30/37 according to CSN EN 206-1. The recipes were always designed for a particular material set (cement, aggregates, additives) that has been used in 21 RMC plants of Ceskomoravsky beton a.s. Tests were done directly in the plants on mixtures with different doses of steel fibres. Fresh concrete was tested or consistency, incl. its changes in time, homogeneity (volume of steel fibres in a volume unit) and pumpability – see Fig. 5. Hardened concrete was tested for compressive strength, splitting tensile strength, flexural tensile strength (strength at the moment when a macro-crack appears and after it appears) – Fig. 6.

Tests done on STEELCRETE resulted in its classification and issuing initial tests for 24 RMC plants. The range of offered compressive strength classes varies from 20 to 50 MPa.

Classification of STEELCRETEs according to TP FC 1-1 [6] by class strength

FC $f_{fc,ck}/f_{fc,ck,cub}$-$f_{fc,tk}/f_{fc,tk,eq}$-$f_{fc,tk,sp}$ e.g. FC40/45-3,2/0,8-3,8

by class of ductility FC $(f_{fc,ck}/\varepsilon_{fc,cu})/f_{fc,ck,cub}$-$(f_{fc,tk}/\ \varepsilon_{fc,tk,fl})/(f_{fc,tk,eq}/\ \varepsilon_{fc,tk,1})$

e.g. FC (40/4,35)/45-(3,2/0,6)/(0,8/22,0)

Fig. 5 : STEELCRETE – pumpability test

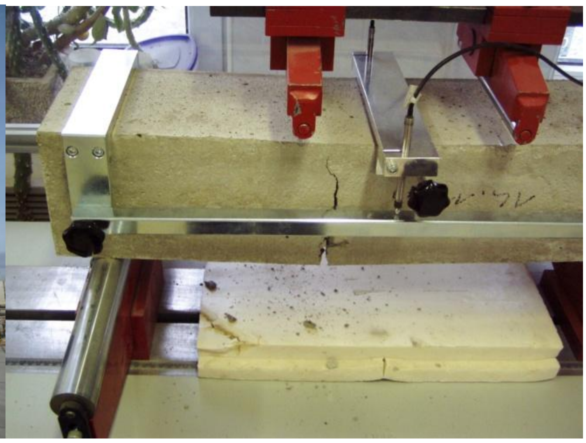

Fig.6 : Flexural tensile strength test

The tests have shown that, according to the design recipes, up to 75 kg steel fibres can be dosed in 1 m^3 of concrete while the homogeneity and pumpability are preserved.

3.5 Final offer for the building market

Having finished all necessary tests and having elaborated final reports concerning initial tests, branded steel-fibre concrete was included into the product portfolio of Ceskomoravsky beton RMC plants in 2010 under the trade-name STEELCRETE, FLOORCRETE – see 3.3.

For the first time branded fibre-concrete STEELCRETE was used in bed-slabs of family homes where they replaced plain concrete in continuous footing – see Fig. 7 and 8.


Fig. 7: Bed-slab in Chyne *Fig. 8:* Placing concrete bed-slab in Kublov

STEELCRETE was also used for further constructional research and development.
Within the grant programme CIDEAS testes were done on prisms made of plain steel-fibre concrete and of steel-fibre concrete combined with reinforcing bars – see Fig. 9. The results were published in the article "Interaction of classic and dispersed reinforcing elements" in BETON TKS magazine [9] and presented at the conference "Concrete technology 2010".
High-grade STEELCTRETE composite structure was produced by the company PAVUS, Veseli n. Luznici, to test fire resistance (see Fig. 10). A resulting paper named "Production, transport and compaction of ready-mixed concrete with high concentration of fibres" was presented at the conference "Special types of concrete 2011" [10].


Fig. 9: Prepared moulds with reinforcement before STEELCRETE was placed
Fig. 10: STEELCRETE placed into steel-concrete composite construction

As stated in 3.3, branded concrete FLOORCRETE is used solely for floors. It simplifies and accelerates the process of their construction. FLOORCRETE completely replaces classic reinforcing nets. The advantages are: no transport and fixation of nets in the construction is needed; shifts and deformations are avoided when concrete is placed – see Fig. 11. These advantages are even more important when reconstructing objects that are difficult to access – see Fig. 12.


Fig. 11: Placing FLOORCRETE – enlargement of airport halls at the Mosnov airport
Fig. 12: Delivery of FLOORCRETE – reconstruction of a floor in Karlovy Vary

4. Conclusion

This article shows that when putting fibre-concrete into practical usage it is advisable to combine long-term results of research and development with requirements of a producer that has clearly defined goals and sufficient resources, both human and technological, to reach this goal.

STEELCRETE and FLOORCRETE - steel-fibre concrete branded products – the properties and application of which are guaranteed and defined beforehand, now offer possibilities for further usage in the building market.

The company product standard could be of some help when preparing standards of higher levels, e.g. national standards (Czech technical standards) or even European ones.

Acknowledgement

This contribution was carried out in the framework of the GAČR 103/09/1073 project and the MSM 021630519 research work.

5. References

[1] DAfStb-Richtlinie Stahlfaserbeton, Deutscher Ausschuss für Stahlbeton-DAfStb, 2005

[2] DBV-Merkblatt Sthlfaserbeton, Deutscher Beton-und Butechnik-Verrein E.V.,2001

[3] Richtlinie Faserbeton, Österreichische Vereinigung für Beton- und Bautechnik,2002

[4] Technical report No.34, Concrete industrial ground floors - A guide to design and construction, Concrete Society GB,

[5] Drátkobetonové konstrukce, Jiří Krátký Karel Trtík, Jan Vodička; issued by: Informační centrum ČKAIT, Praha 1999

[6] TP FC 1-1 Technické podmínky 1: Vláknobeton – Část 1, řešitelský kolektiv projektu MPO pod vedením doc.Ing. Aleny Kohoutkové, CSc.; issued by: Českomoravský beton, a.s., December 2007

[7] PN ČMB 01-2008, Vláknobeton (FC)- Specifikace, vlastnosti, výroba a shoda, BETOTECH, s.r.o, ČVUT v Praze, Fakulta stavební, Katedra betonových a zděných konstrukcí, červen 2008

[8] STO 060-028542 Beton pevnostních tříd C12/15(B15) a vyšší pro konstrukce pozemních, inženýrských a dopravních staveb, typ/varianta : vláknobeton, vydal TZÚS Praha, 22.9.2008

[9] Spolupůsobení klasické a rozptýlené výztuže)Interaction of classic and fibre reinforcement), Jan L. Vítek, Stanislav Smiřinský, BETON TKS č.2/2010, Praha 2010

[10] Výroba, doprava a hutnění transportbetonu s vysokou koncentrací vláken, Jan Vodička, Milada Mazurová, Stanislav Smiřinský, Vladimír Veselý, konference Speciální betony 2010.

[11] ČSN EN 1992-1-1 Eurokód 2: Navrhování betonových konstrukcí