BUDAPEST UNIVERSITY OF TECHNOLOGY AND ECONOMICS
Department of Mechanics, Materials and Structures
Laboratory of Materials and Structures

THE BIG CRACK 2012
laboratory presentation

STEEL, SYNTHETIC MACRO AND MICRO FIBRE REINFORCED BEAMS RESEARCH

November 9. 2012

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KERA Bt.

The ZWICK Z150 universal material testing machine was provided by the contest TÁMOP 4.2.1/B-09/1/KMR-2010-0002.

1. Introduction

The goal of this research was to test independently of commercial interests those steel and synthetic fibres being distributed in Hungary. Our aim was to establish an overall picture of the fibres and with the help of this research allow engineers to be able to select the most suitable fibre for their work, whether it be an industrial floor, precast element or even a tramline.

The word *synthetic fibre* mainly refers to *micro fibre* in Hungary; however there are *micro* and *macro synthetic fibres* present as well on the market. For the purposes of the avoidance of doubt, we refer to each of the types of fibres as follows:
- **micro fibres**, which have no effect on the structure from a static calculation point of view; such fibres being effective only at the fresh concrete stage to control early micro cracks, and
- **macro fibres**, which like steel fibres have a consideration for the purpose of static calculation.

We also researched fibrillated and mono micro fibres and ribbed, twisted and waved macro fibres. We made concrete beams without fibres and steel fibre reinforced beams with two different dosages as well, for comparison purposes.

2. Testing specimens

2.1. Geometry

The test beam specimens measured 600 mm long with a section of 150 x 150 mm. The beams were notched on the bottom to a thickness of 3 mm and 25 mm depth, the loading was applied above the notch.

Test specimens were made at the concrete laboratory of MAPEI on 5-7 of September, 2012.

Signs of the specimens:

ETALON	yy.mm.dd	number of the specimen
STEEL1-2	(date of the made of the specimen)	
MACRO1-5		
MICRO1-2		

2.2. Concrete

Fibre reinforced concrete in Hungary is mostly used for industrial floors, so we choose a concrete that is suitable for that purpose.

Concrete type: **C30/37-XC4-XD2-XF1-XA1-XV2(H)-24-F3-CEM 42,5 industrial floor**

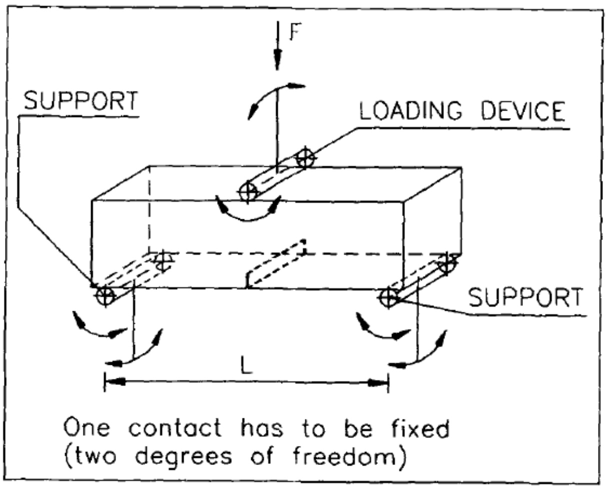
The exact mix properties can be found in Annex A.

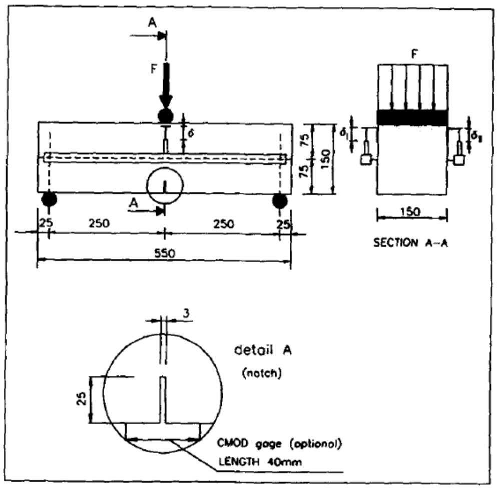
2.3. Fibres

The name of the fibres, photos and documents are set out in the results section. The geometry of the fibre, shape, material and the notes during the mixing (i.e. any mixing problems) are also stated.

3. Test method

The testing method is as stated in picture 1.





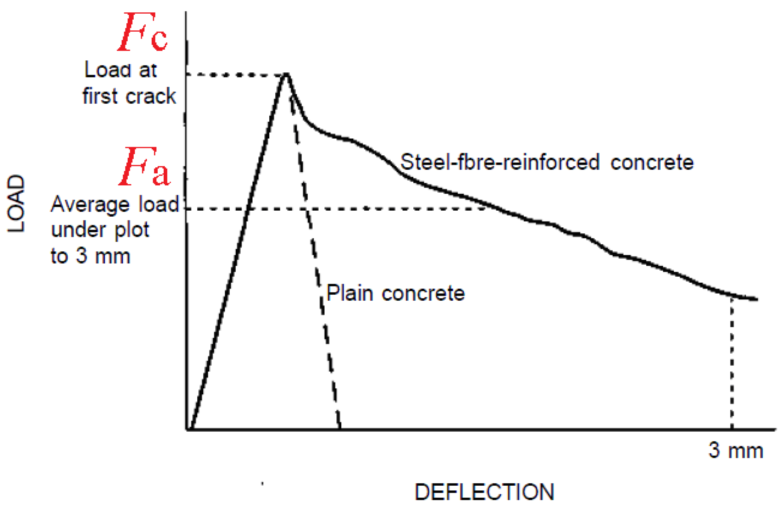
picture 1: testing method recommended by RILEM

We made the test according to the following guideline:
RILEM TC 162-TDF : Test and design methods for steel fibre reinforced concrete (Vandewalle, L., et al., 2002).

3.1. R_{e3}

The most suitable design recommendation for designing industrial floors is the TR34 – Concrete industrial ground floors (The Concrete Society UK, 2003). The use of the R_{e3} number for designing FRC floors is defined in the Japanese guideline JSCE SF-4 (Japanese Society of Civil Engineers, 1985). The R_{e3} number is the average of the residual stress and the flexural strength divided in percentage (picture 2):

$$R_{e3} = \frac{F_a}{F_c} (\%)$$



picture 2: the calculation of the residual stress (JSCE SF-4)

3.2. Load-deflection and load-CMOD diagrams

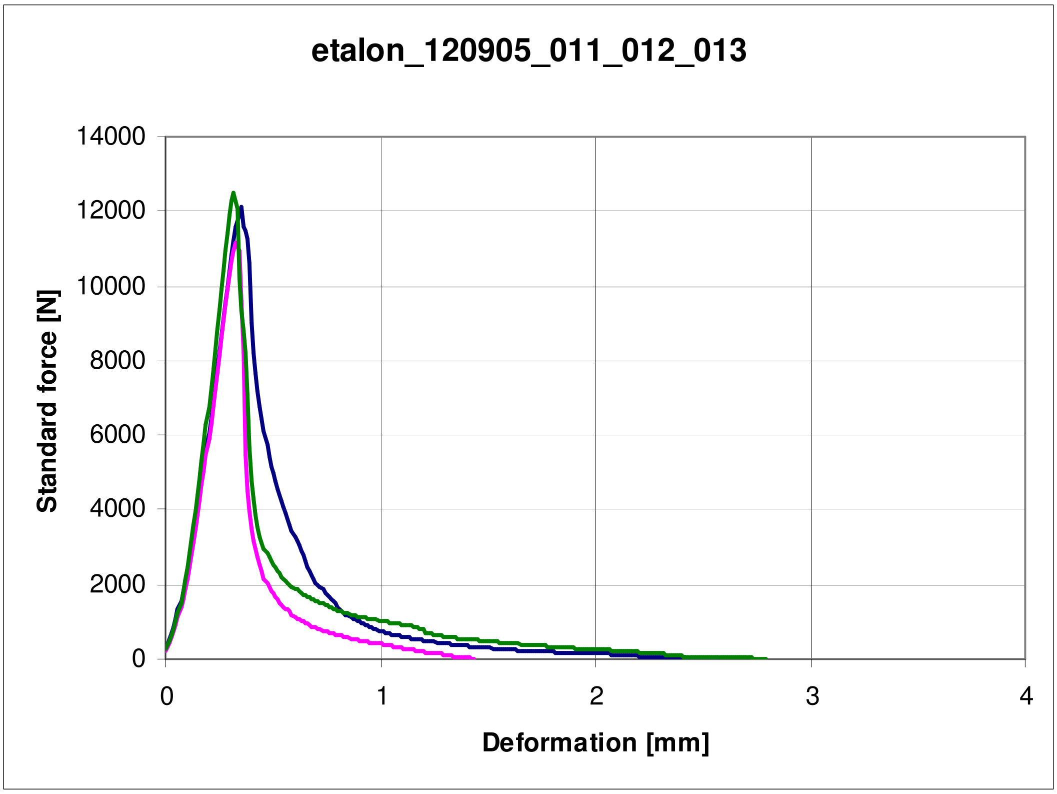
Most of the guidelines use the load-deflection diagram to define the stress-strain diagram, but there are also some that prefer the load-CMOD (Crack Mouth Opening Displacement). This value is directly measured on the crack opening, whist the stress-strain diagram could be defined more accurately.

We measured both results during the research.

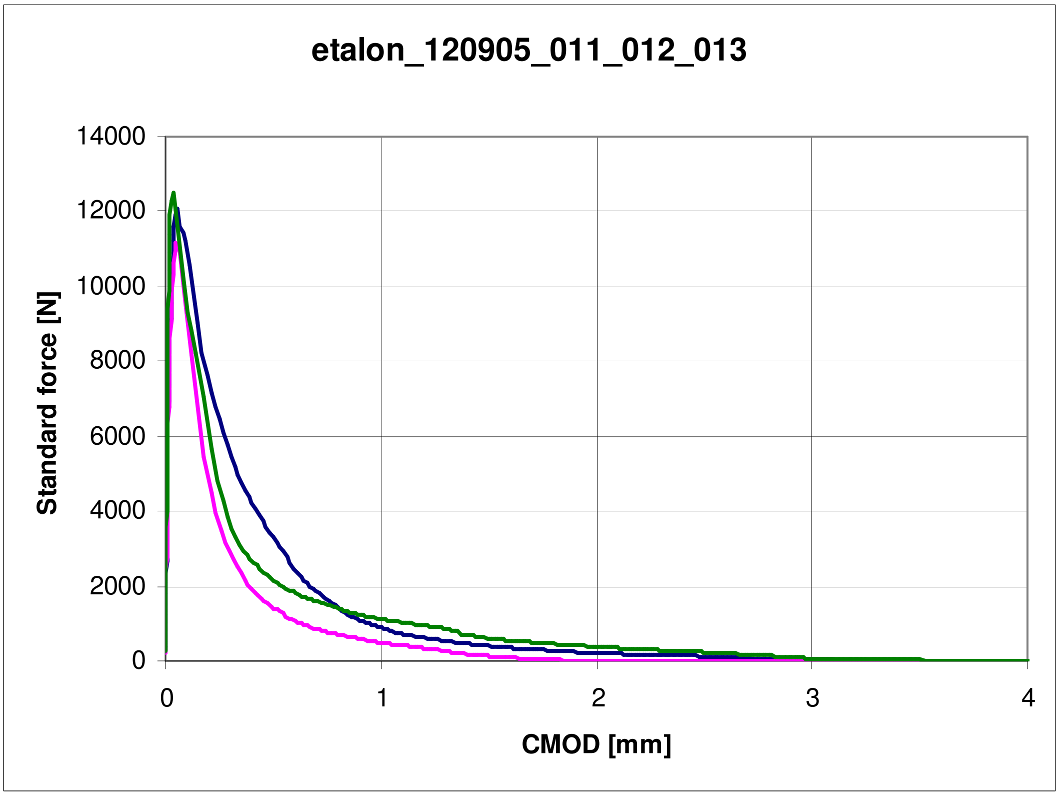
4. Results

4.1. Concrete beam

4.1.1. Load-deflection diagram



4.1.2. Load-CMOD diagram



4.1.3. Photos

120905_011

120905_012

120905_013

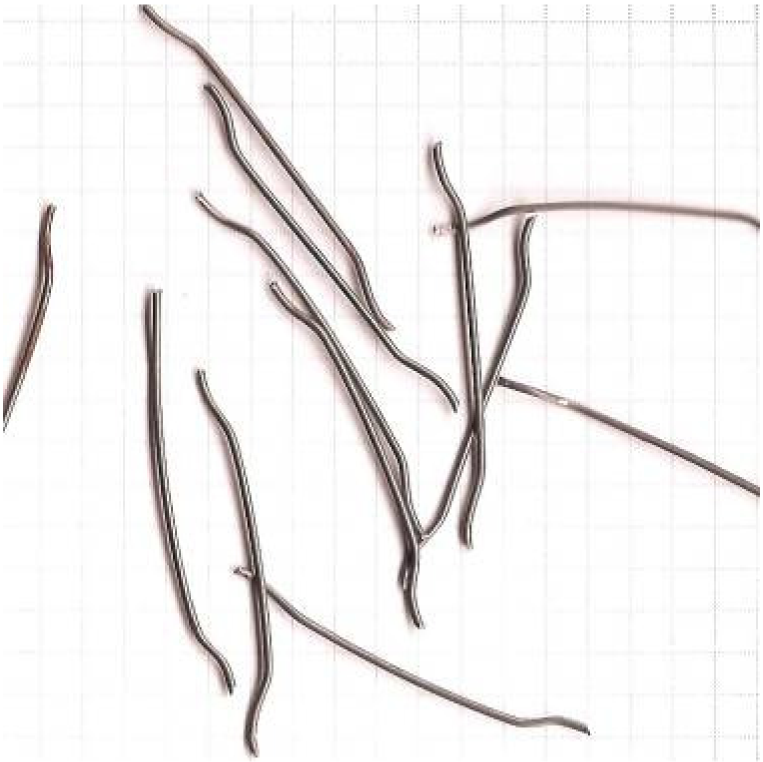
4.2. Steel fibre reinforced beams – 50 mm hooked end steel fibre, dosage 20 kg

Details of the fibre

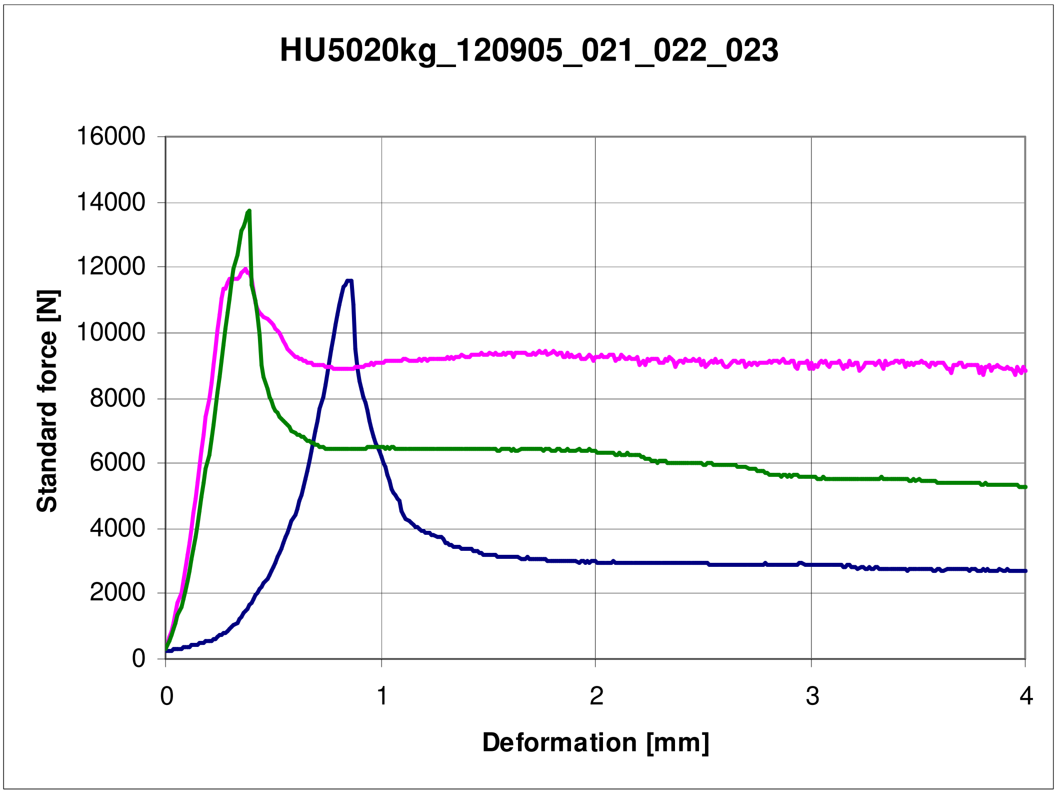
type:	end hooked steel fibre
section:	circle
length:	50 mm
diameter:	1,1 mm
weight:	30,36 gram / 100
number in 1 kg:	3293 db
dosage:	20 kg/m^3
volume%:	0,2586 m^3/m^3

Notes

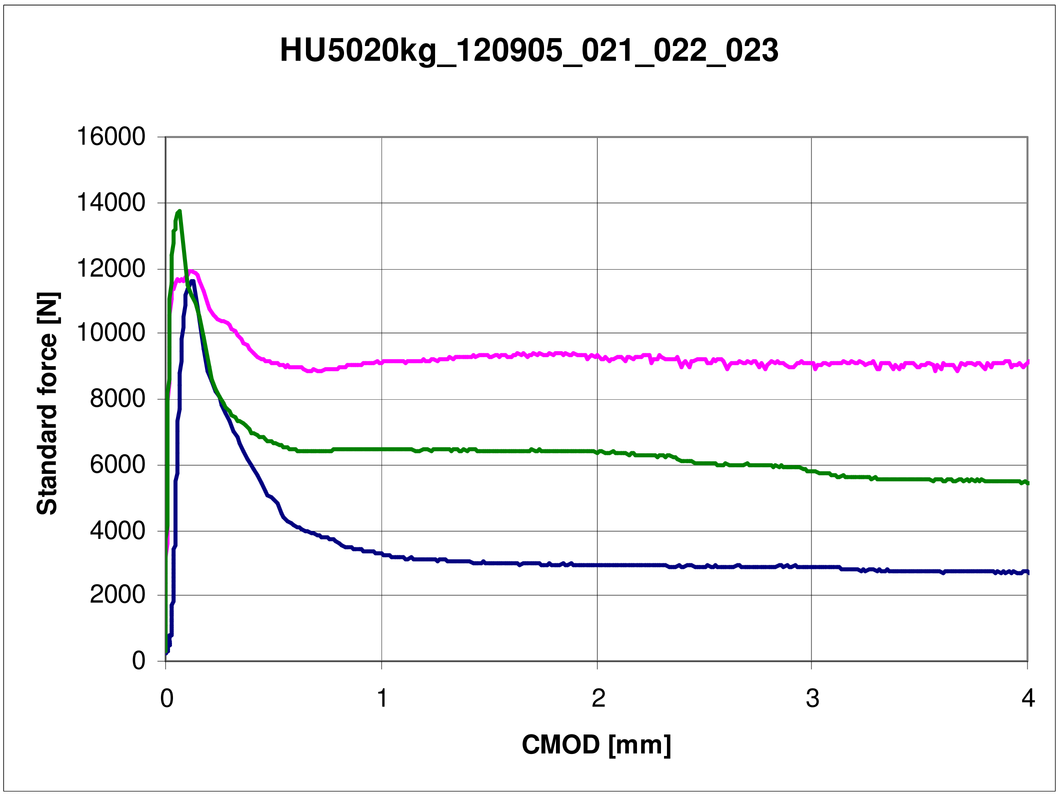
The fibre at the dosage above mixed well, the fresh fibre reinforced concrete was homogenous and easy to compact.



4.2.1. Load-deflection diagrams



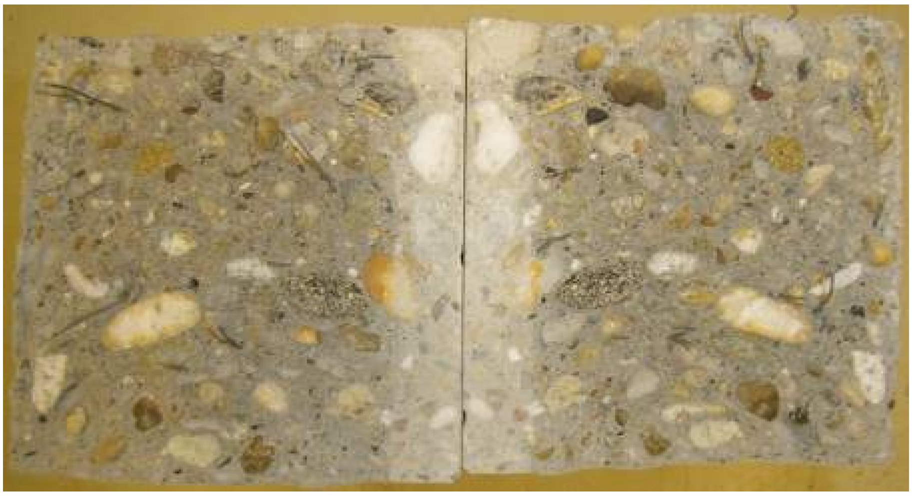
4.2.2. Load-CMOD diagrams



4.2.3. Photos

120905_021

120905_022



120905_023

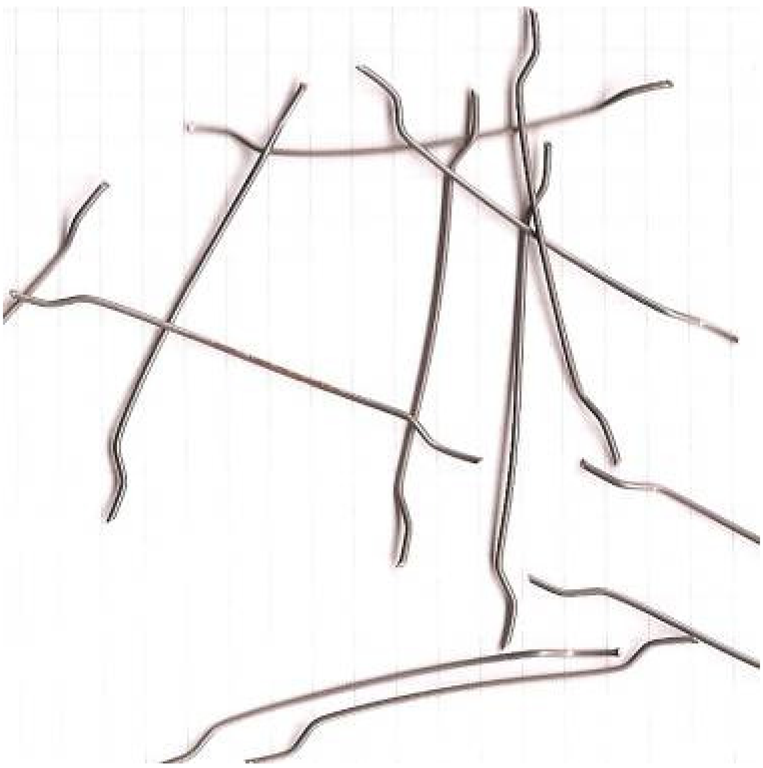
4.3. Steel fibre reinforced beams – 60 mm hooked end steel fibre, dosage 20 kg

Details of the fibre

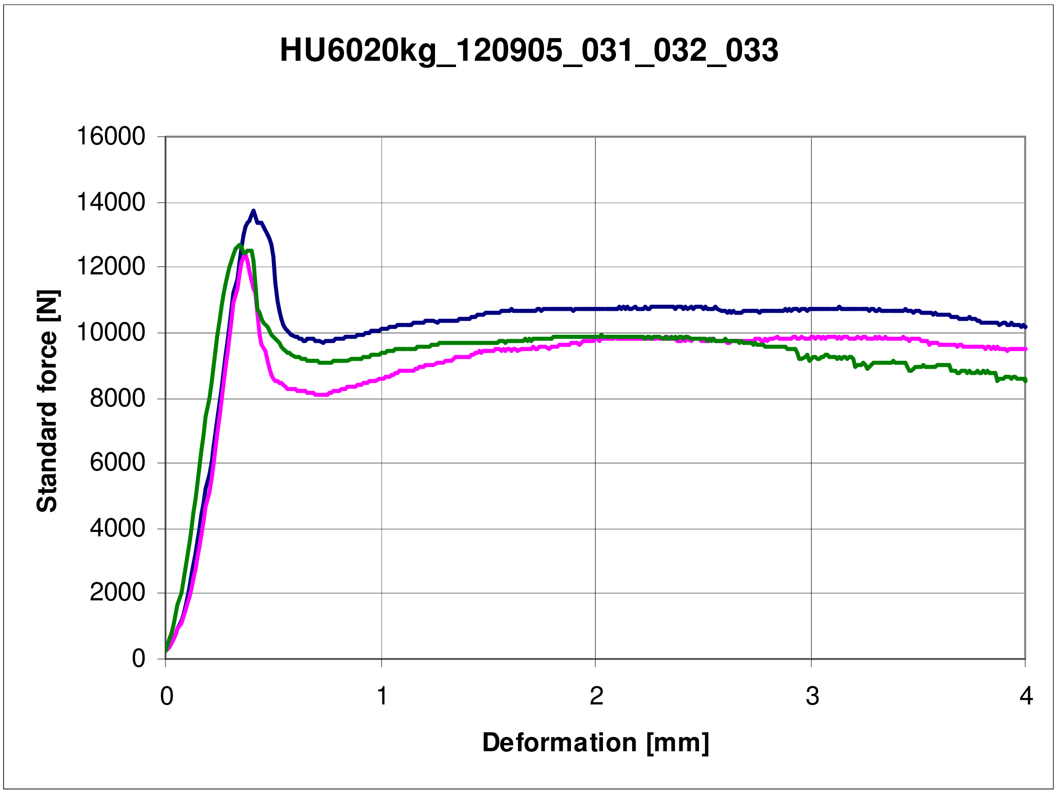
type:	end hooked steel fibre
section:	circle
length:	60 mm
diameter:	0,9 mm
weight:	27,5 gram/ 100
number in 1 kg:	3636 db
dosage:	20 kg/m^3
volume%:	0,2476 m^3/m^3

Notes

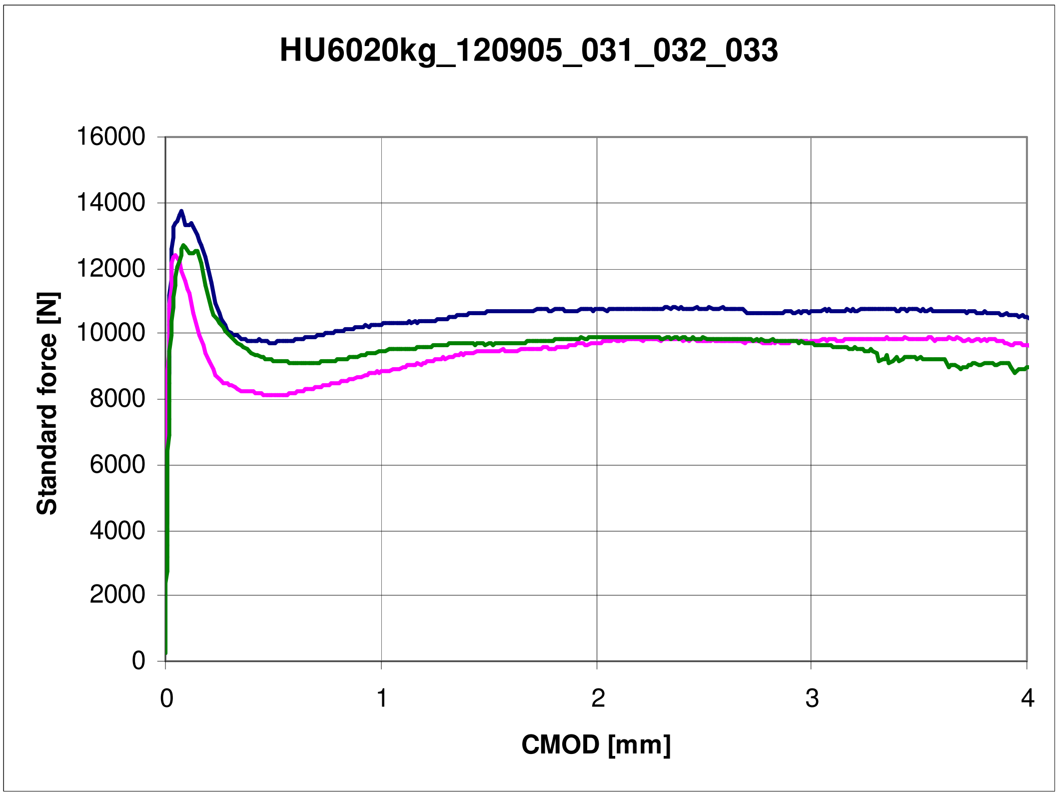
The fibre at the dosage above mixed well, the fresh fibre reinforced concrete was homogenous and easy to compact.



4.3.1. Load-deflection diagrams



4.3.2. Load-CMOD diagrams



4.3.3. Photos

120905_031

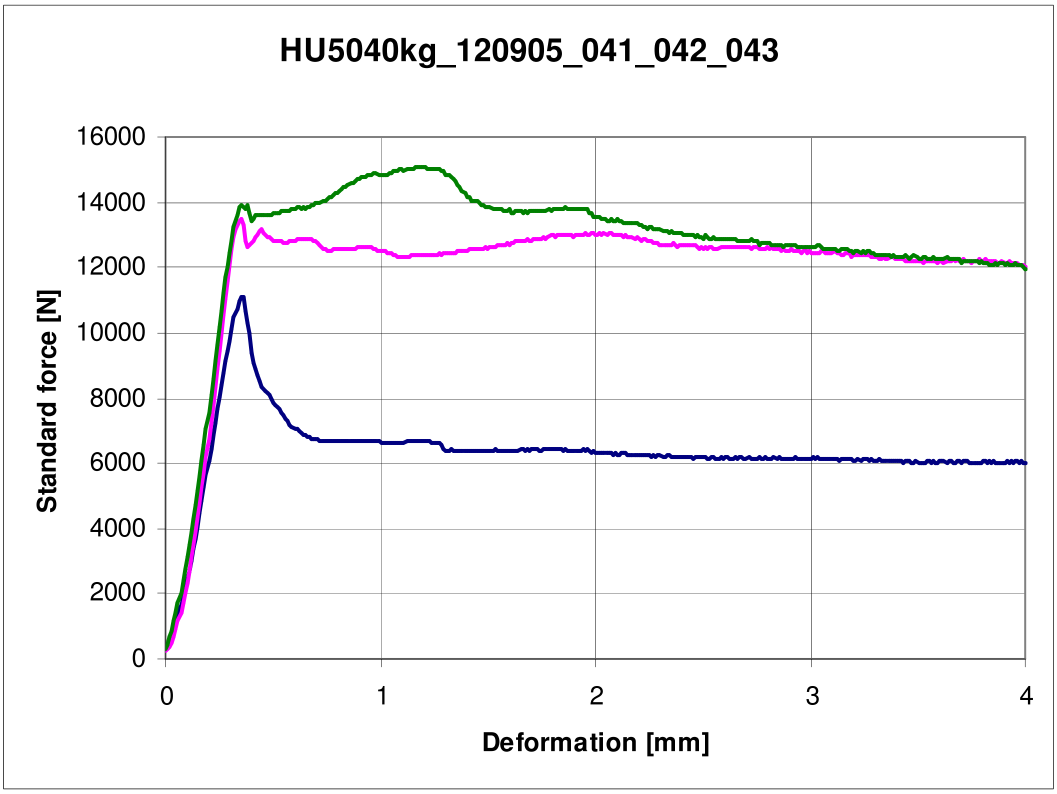
120905_032

120905_033

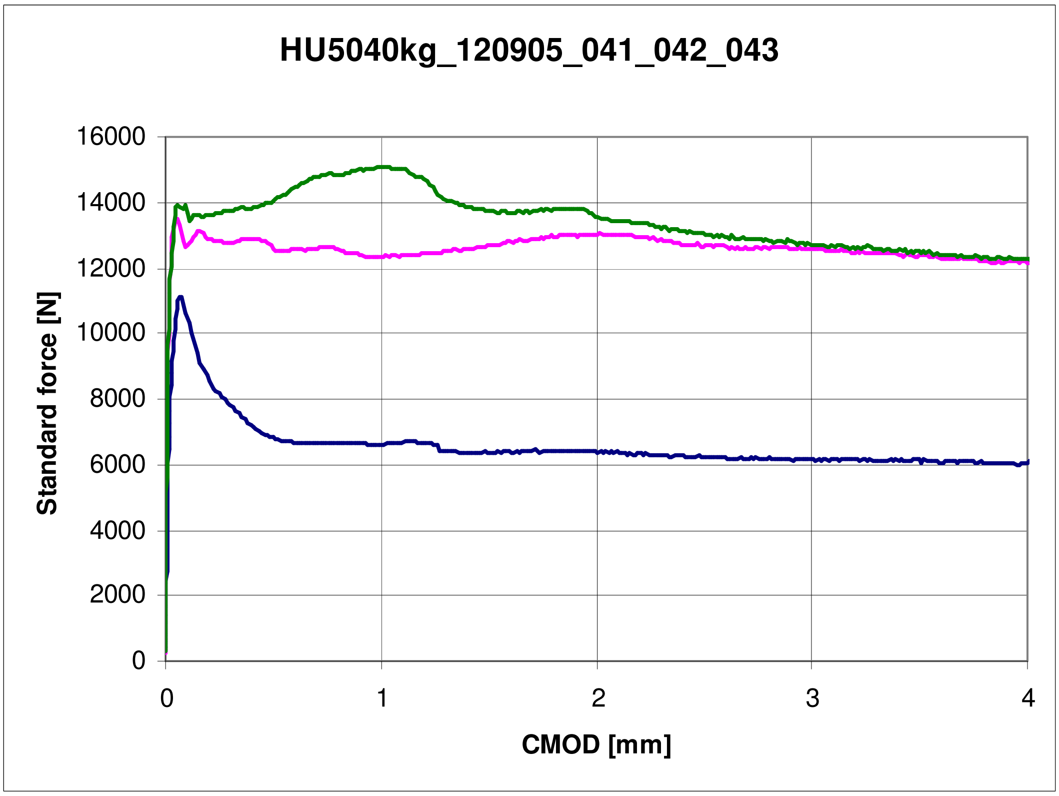
120905_033: fibres concentration at the edge

4.4. Steel fibre reinforced beams – 50 mm hooked end steel fibre, dosage 40 kg
details at 4.2

4.4.1. Load-deflection diagrams



4.4.2. Load-CMOD diagrams

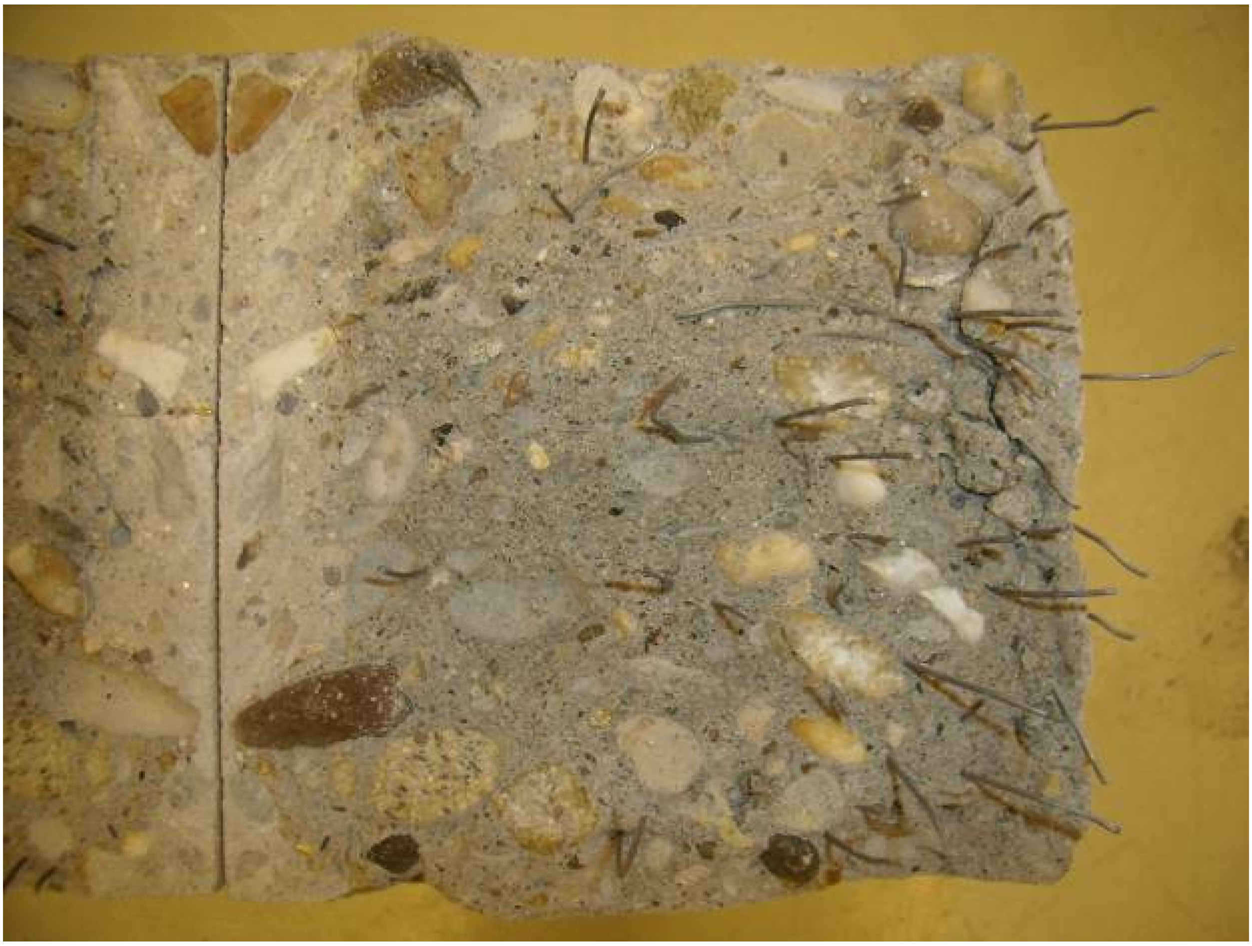


4.4.3. Photos

120905_041

120905_042

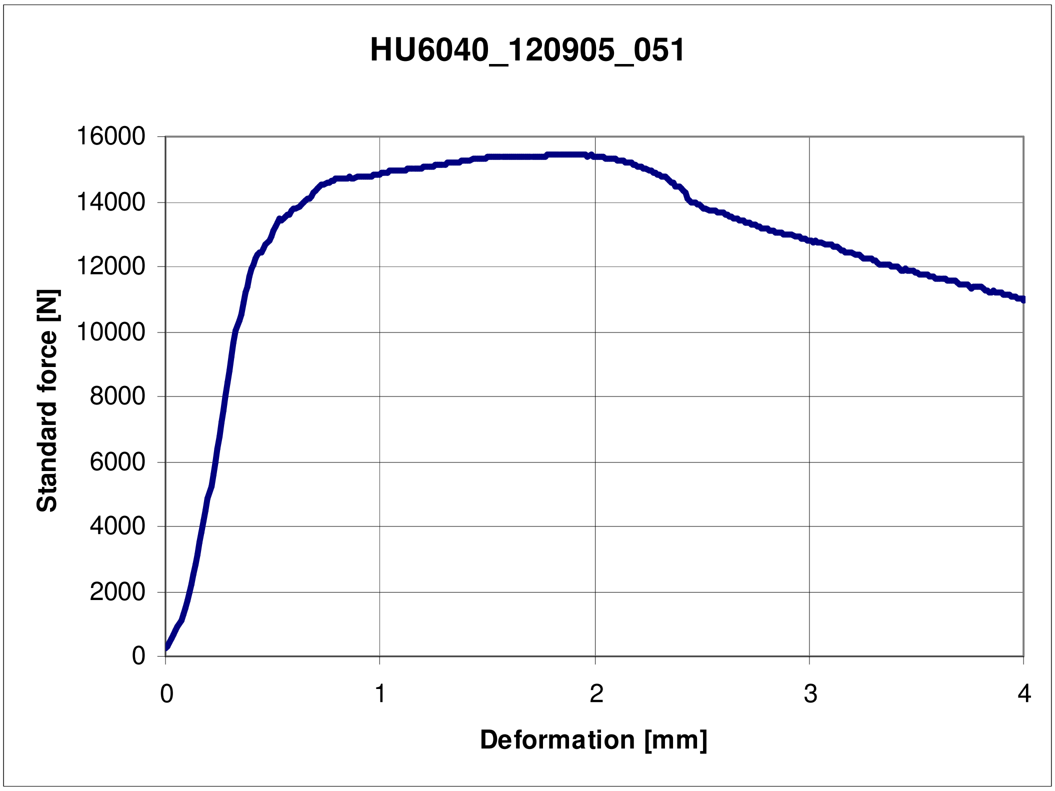
120905_043



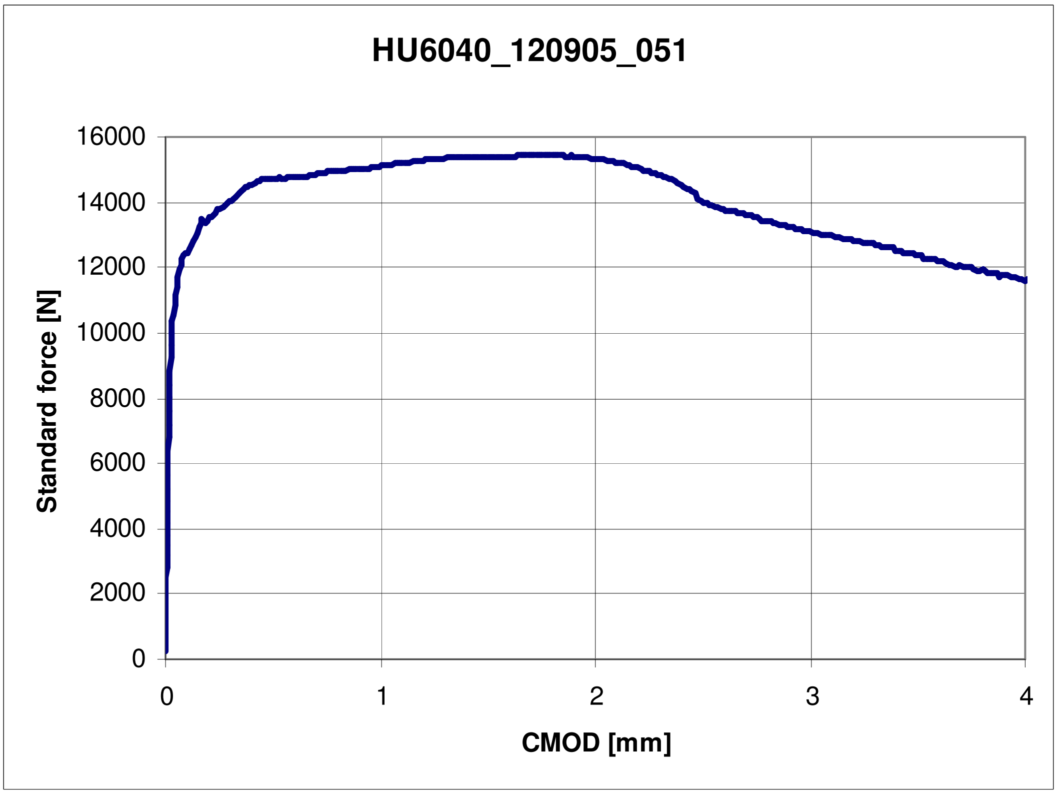
120905_042: fibre concentration at the upper part of the beam

4.5. Steel fibre reinforced beams – 60 mm hooked end steel fibre, dosage 40 kg
details at 4.3.

4.5.1. Load-deflection diagram



4.5.2. Load-CMOD diagram



4.5.3. Photos

120905_051

120905_051: fibres balling

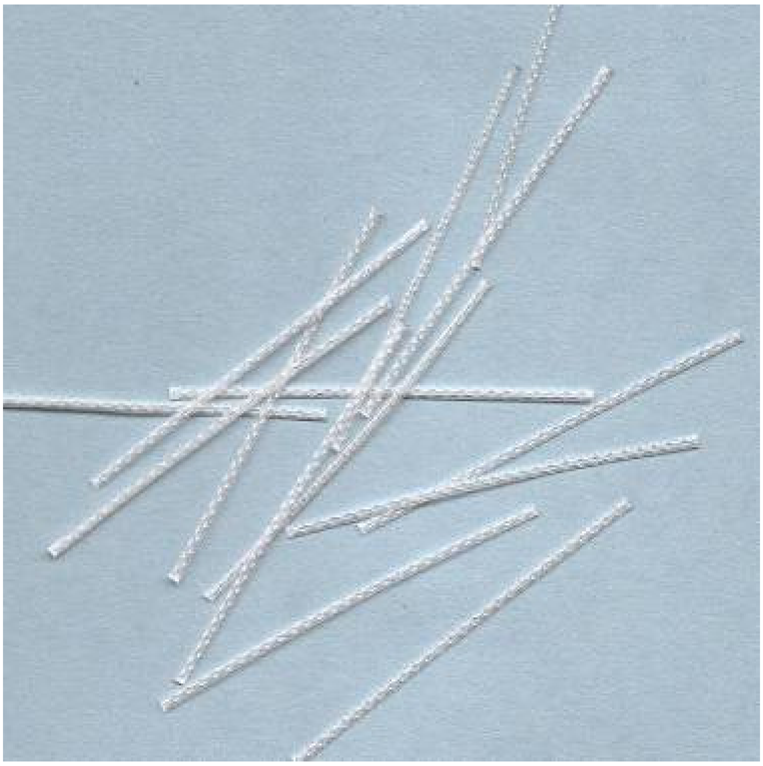
4.6. MAKRO1 – dosage 5 kg

<u>Details of the fibre</u>

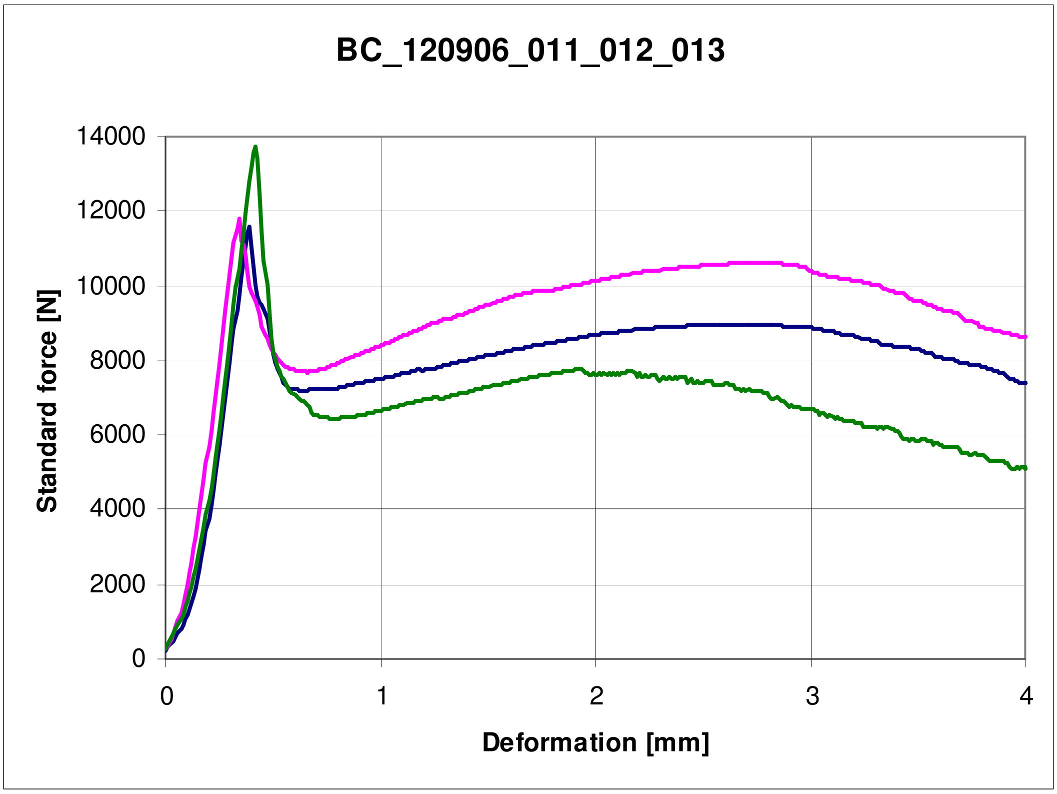
type:	embossed surface polypropylene fibre
section:	oval
length:	48 mm
diameter:	1,3 x 0,5 mm
weight:	1,66 gram / 100 db
number in 1 kg:	60241 db
dosage:	5 kg/m^3
volume%:	0,8674 m^3/m^3

<u>Notes</u>

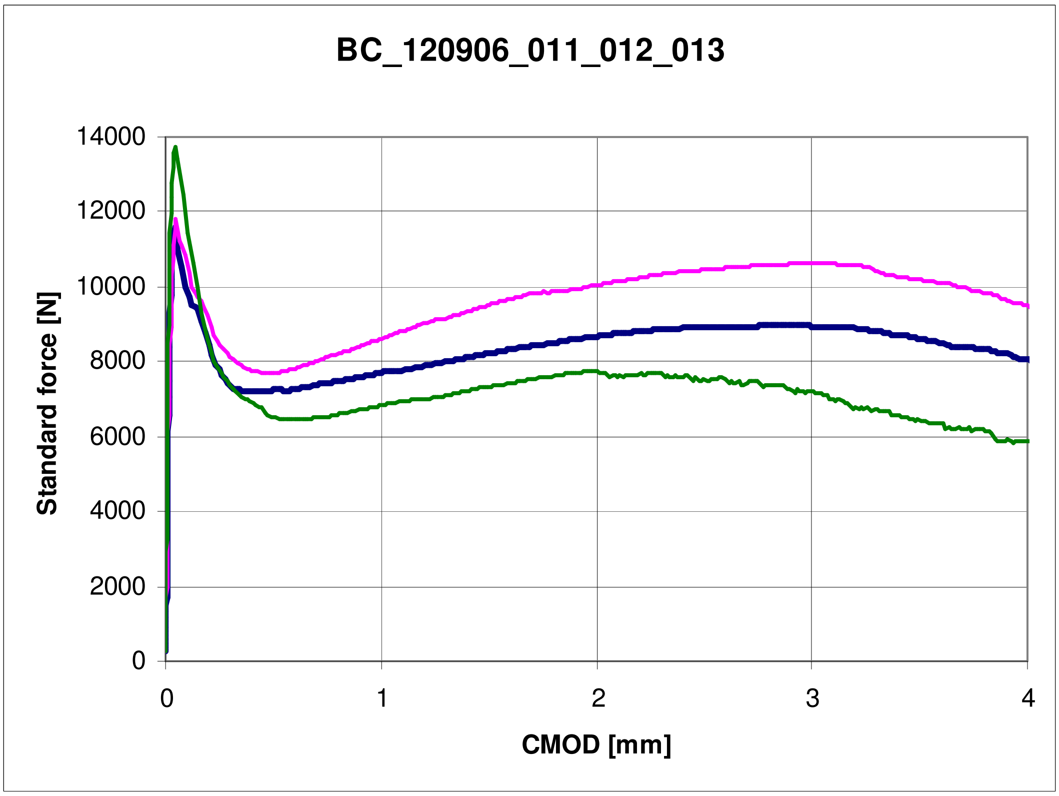
The fibre at the dosage above mixed well, the fresh fibre reinforced concrete was homogenous and easy to compact.



4.6.1. Load-deflection diagram



4.6.2. Load-CMOD diagram



4.6.3. Photos

120906_011

120906_012

120906_013

4.7. MAKRO2 – dosage 5 kg

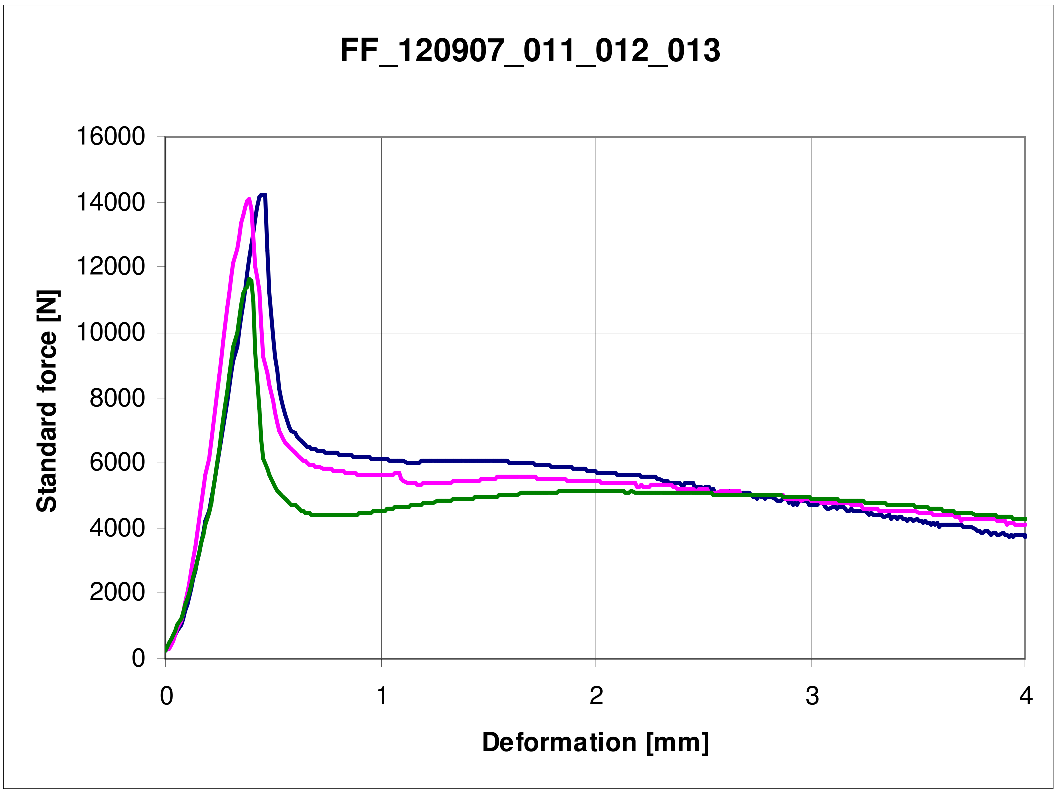
Details of the fibre

type:	twisted macro and fibrillated micro fibre
section:	twisted mono
length:	50 mm
diameter:	-
weight:	-
number in 1 kg:	-
dosage:	5 kg/m^3
volume%:	-

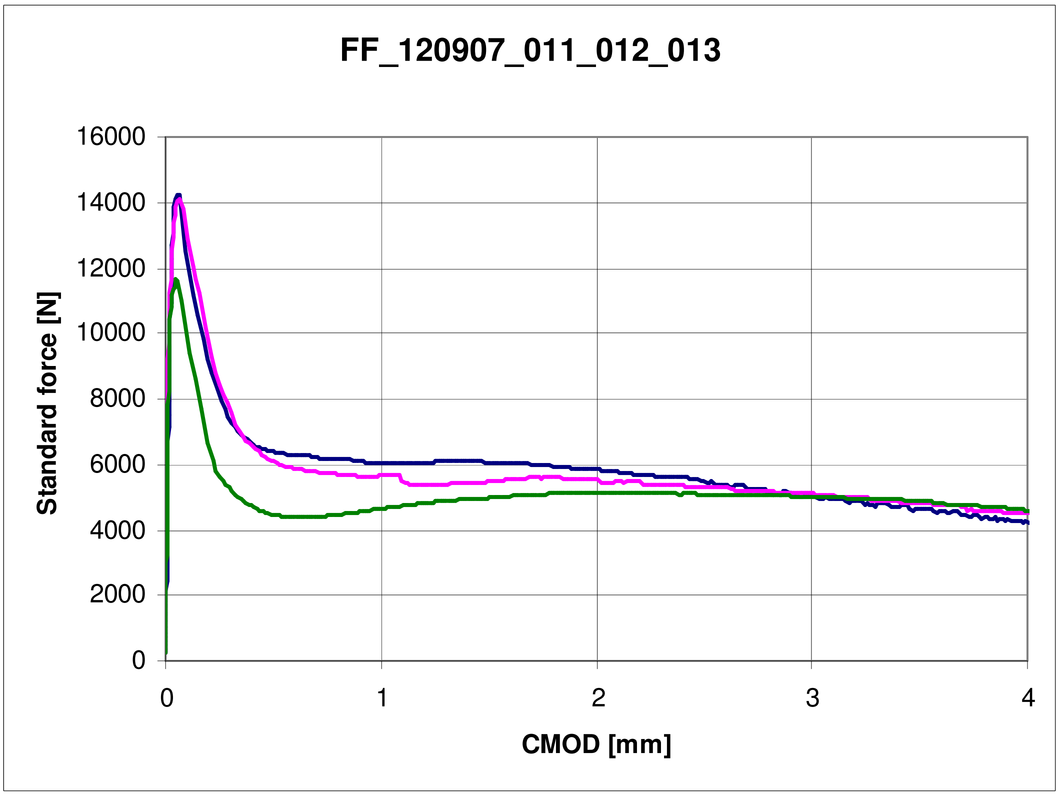
Notes

The fibre at the dosage above was hard to mix, the addition of plasticizer didn't help to solve this problem. An alternative mix design is needed for this type of fibre.

4.7.1. Load-deflection diagram



4.7.2. Load-CMOD diagram



4.7.3. Photos

120907_011

120907_012

120907_013

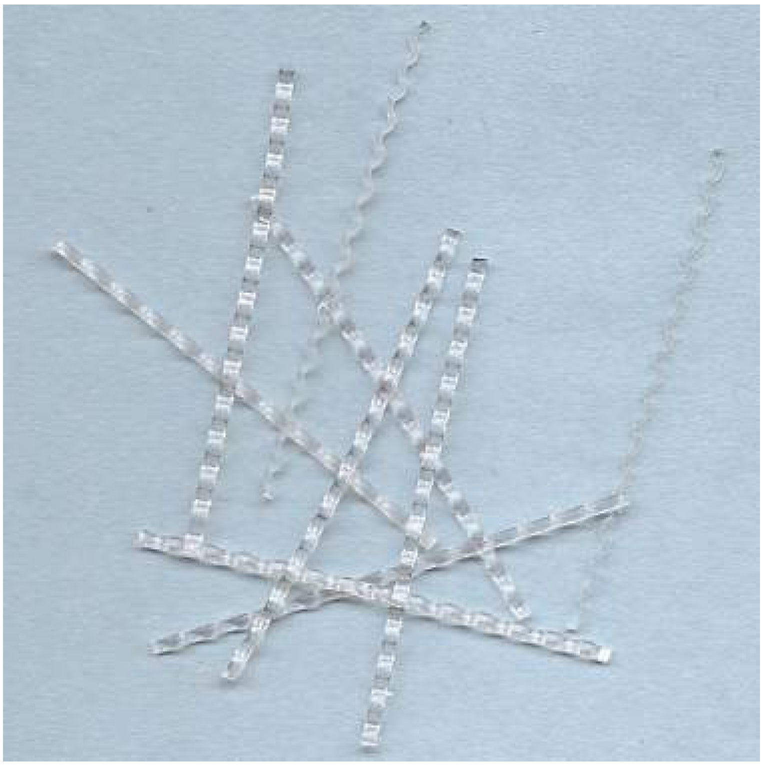
4.8. MAKRO3 – dosage 5 kg

Details of the fibre

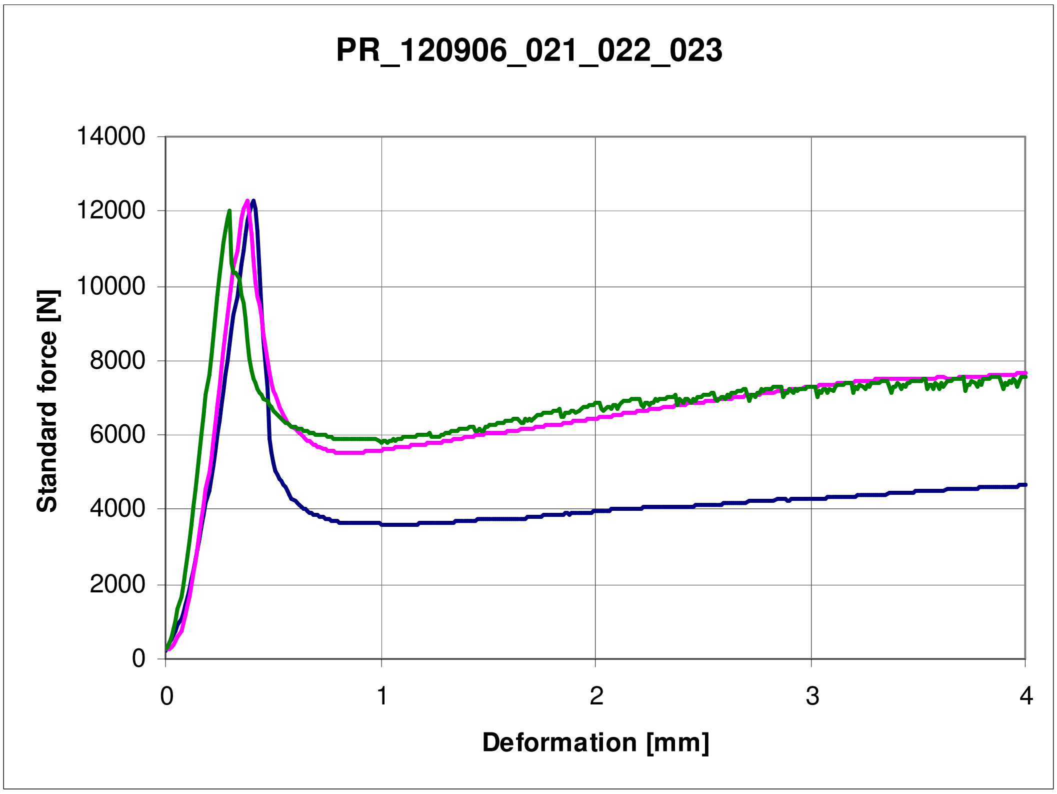
type:	waved polypropylene fibre
section:	rounded rectangle
length:	45 mm
diameter:	1,3x0,7 mm
weight:	3,1 gram / 100 db
number in 1 kg:	32258 db
dosage:	5 kg/m^3
volume%:	0,6604 m^3/m^3

Notes

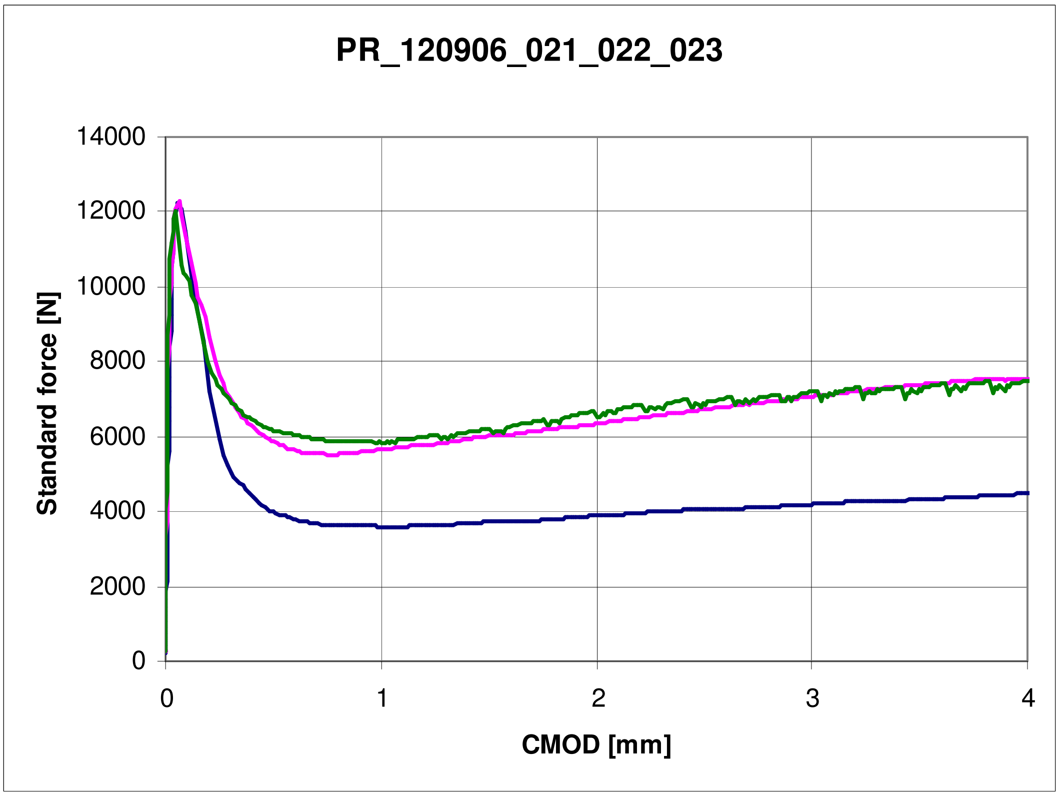
The fibre at the dosage above mixed well, the fresh fibre reinforced concrete was homogenous and easy to compact.



4.8.1. Load-deflection diagram



4.8.2. Load-CMOD diagram



4.8.3. Photos

120906_021

120906_022

120906_023

4.9. MAKRO4 – dosage 5 kg

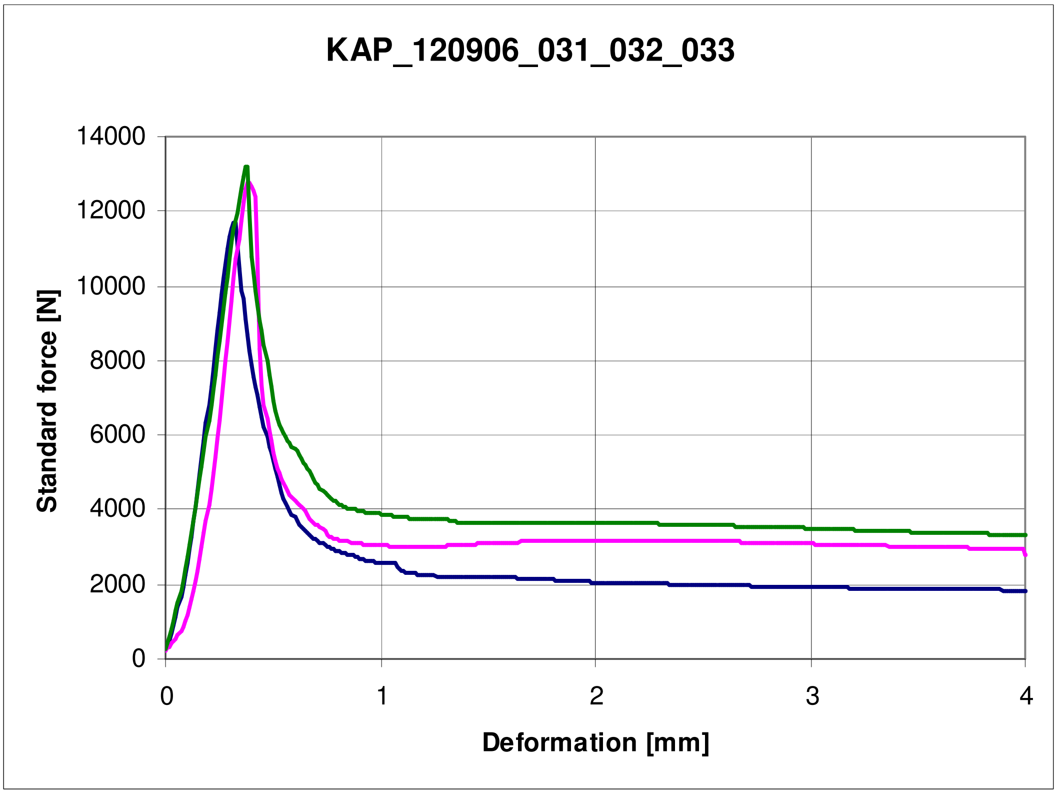
<u>Details of the fibre</u>

type:	waved polypropylene fibre
section:	rounded rectangle
length:	40 mm
diameter:	0,9x1,2 mm
weight:	3,2 gram / 100 db
number in 1 kg:	31250 db
dosage:	5 kg/m^3
volume%:	0,675 m^3/m^3

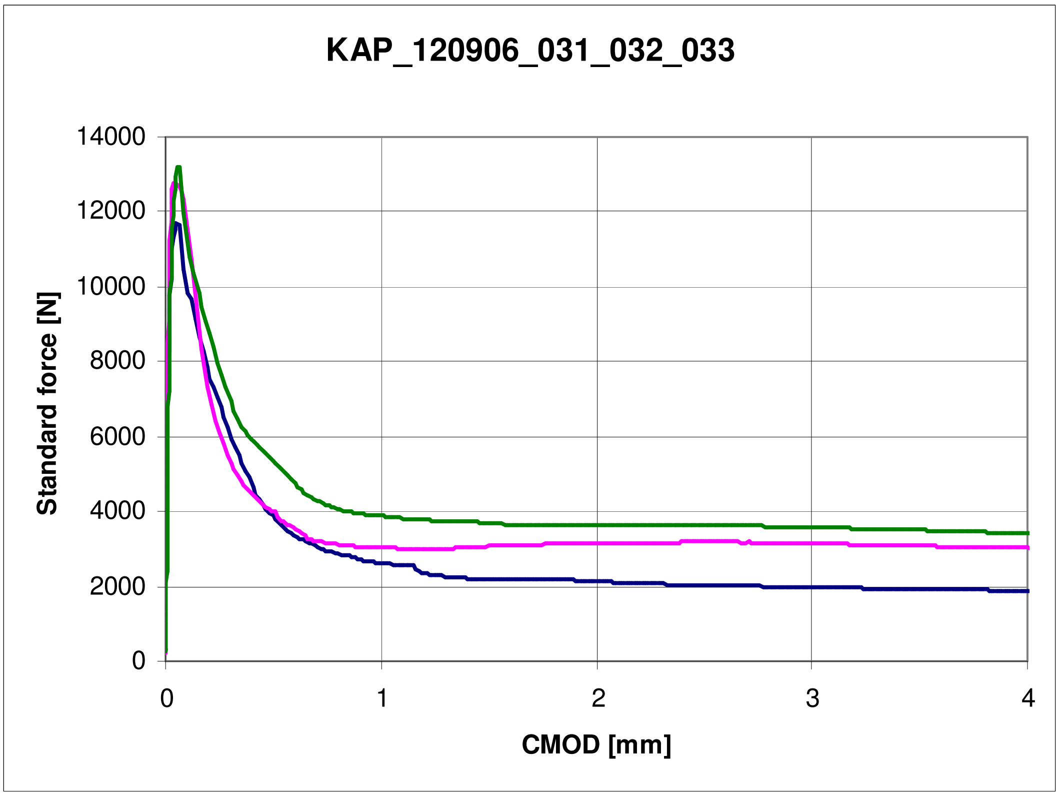
<u>Notes</u>

The fibre of the dosage above mixed well, the fresh fibre reinforced concrete was homogenous and easy to compact.

4.9.1. Load-deflection diagram



4.9.2. Load-CMOD diagram



4.9.3. Photos

120906_031

120906_032

120906_033

1521 Budapest, Műegyetem rakpart 3. K épület II. 42. Tel: 463-1317 Fax: 463-1773

4.10. MAKRO5 – dosage 5 kg

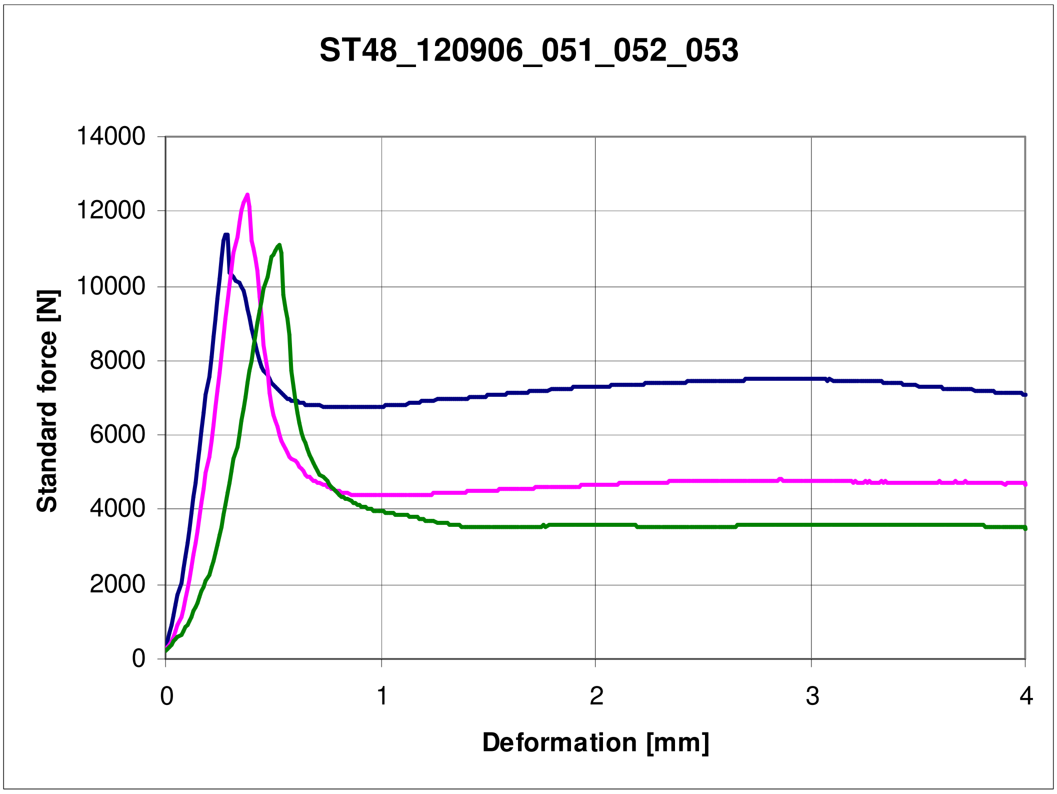
Details of the fibre

type:	waved polypropylene fibre
section:	rounded rectangle
length:	48 mm
diameter:	0,8x1,1 mm
weight:	2,02 gram / 100 db
number in 1 kg:	49505 db
dosage:	5 kg/m^3
volume%:	1,0455 m^3/m^3

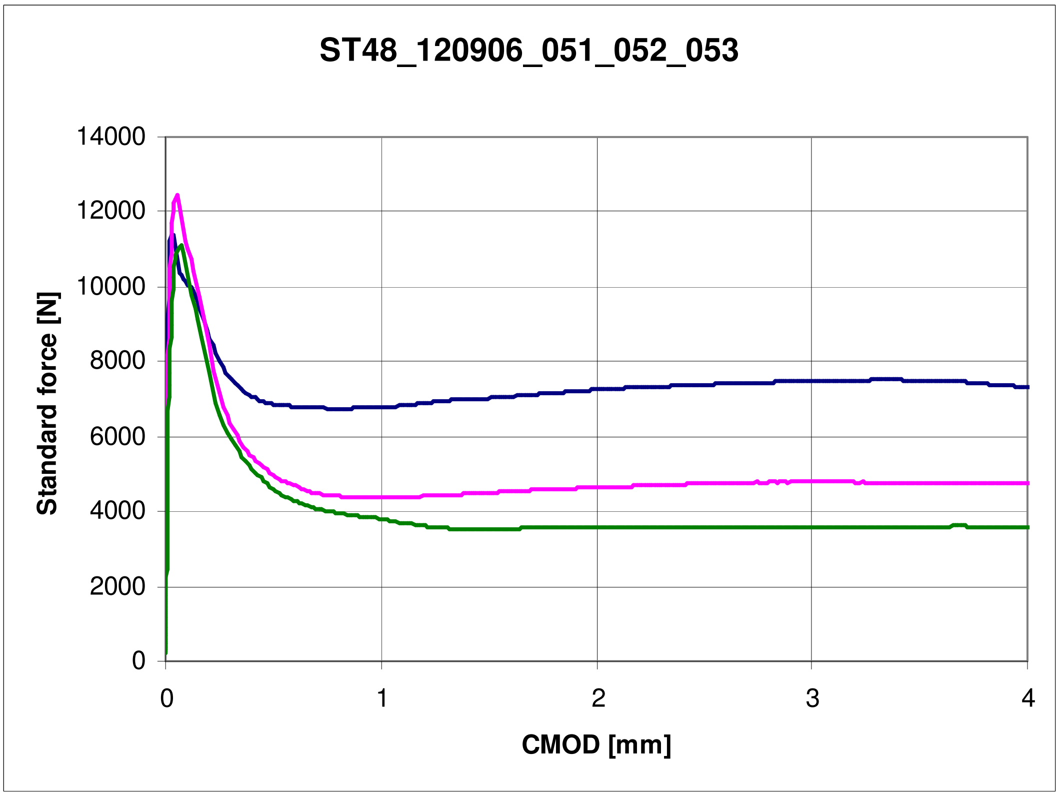
Notes

The fibre at the dosage above mixed well, the fresh fibre reinforced concrete was homogenous and easy to compact.

4.10.1. Load-deflection diagram



4.10.2. Load-CMOD diagram



4.10.3. Photos

120906_051

120906_052

120906_053

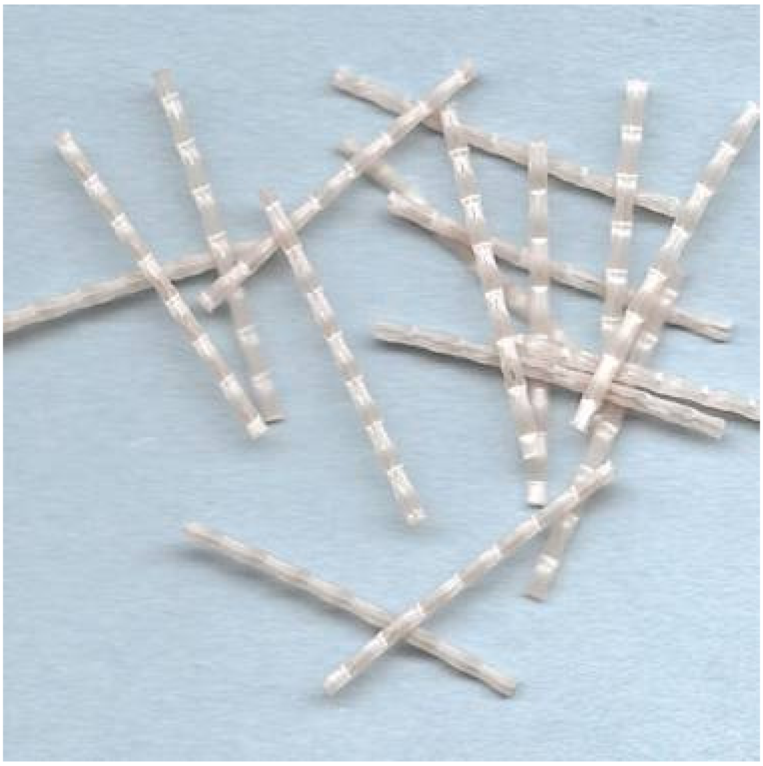
4.11. MAKRO6 – dosage 5 kg

Details of the fibre

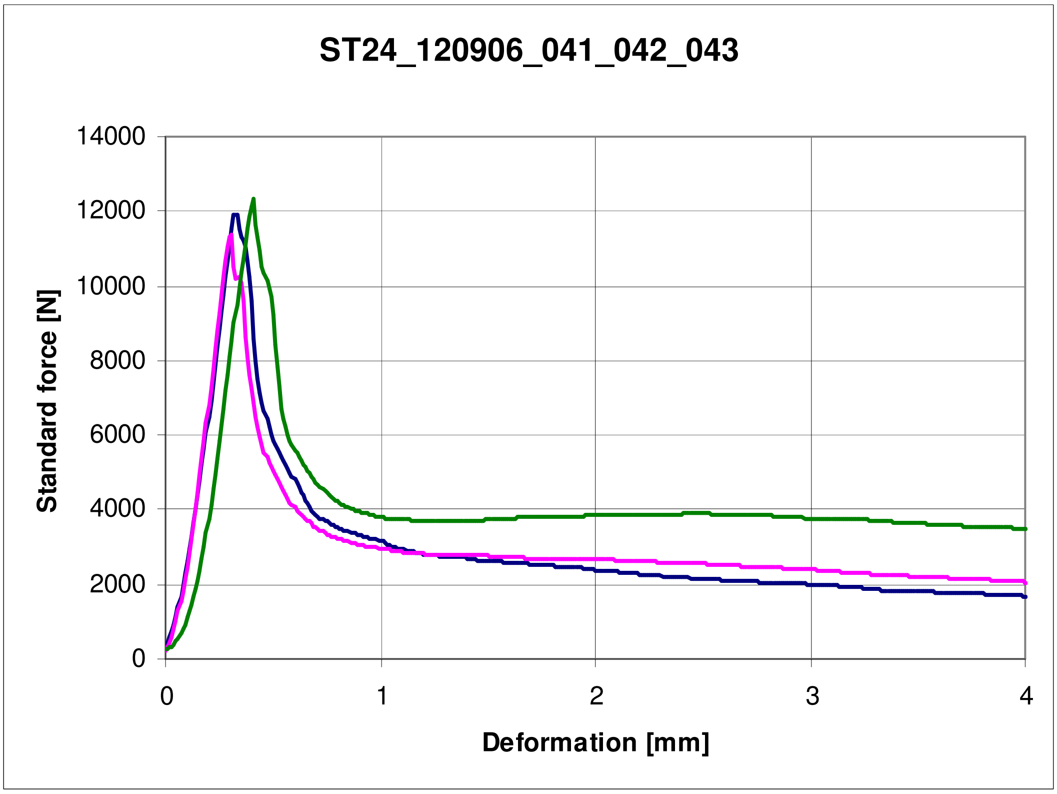
type:	waved polypropylene fibre
section:	rounded rectangle
length:	24 mm
diameter:	0,7x1,2 mm
weight:	1,14 gram / 100 db
number in 1 kg:	87719 db
dosage:	5 kg/m^3
volume%:	0,8842 m^3/m^3

Notes

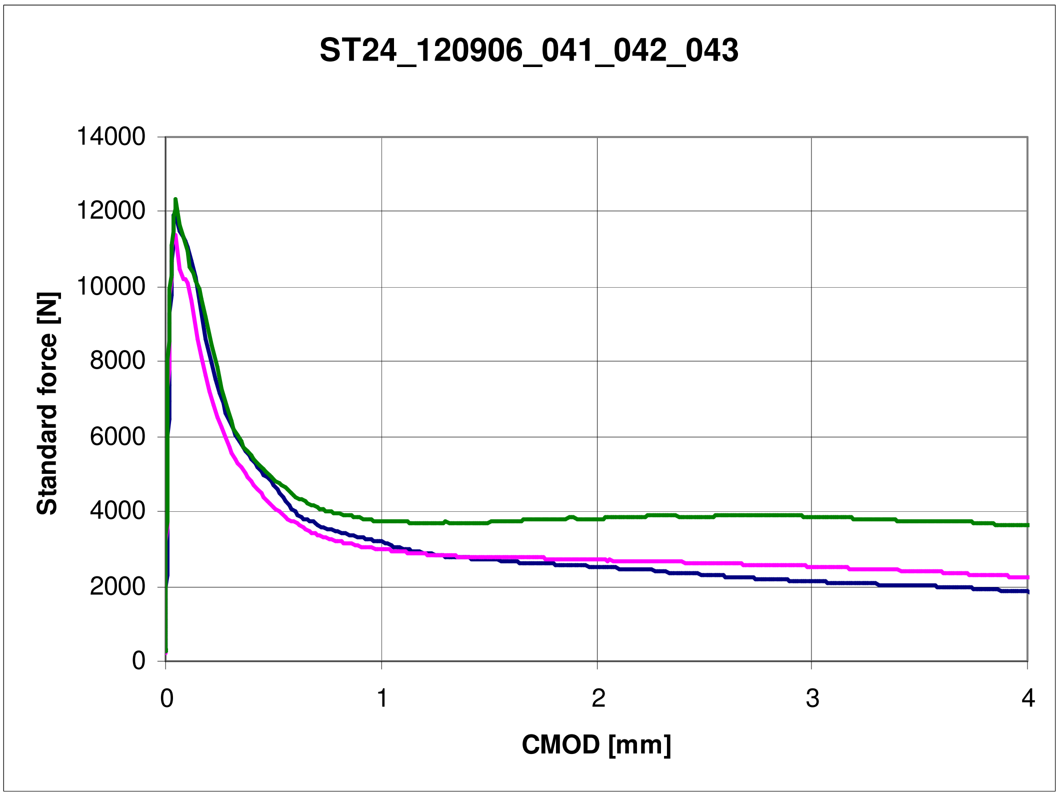
The fibre at the dosage above mixed well, the fresh fibre reinforced concrete was homogenous and easy to compact.



4.11.1. Load-deflection diagram



4.11.2. Load-CMOD diagram



4.11.3. Photos

120906_041

120906_042

120906_043

4.12. MIKRO1 (fibrillated) – dosage 1 kg

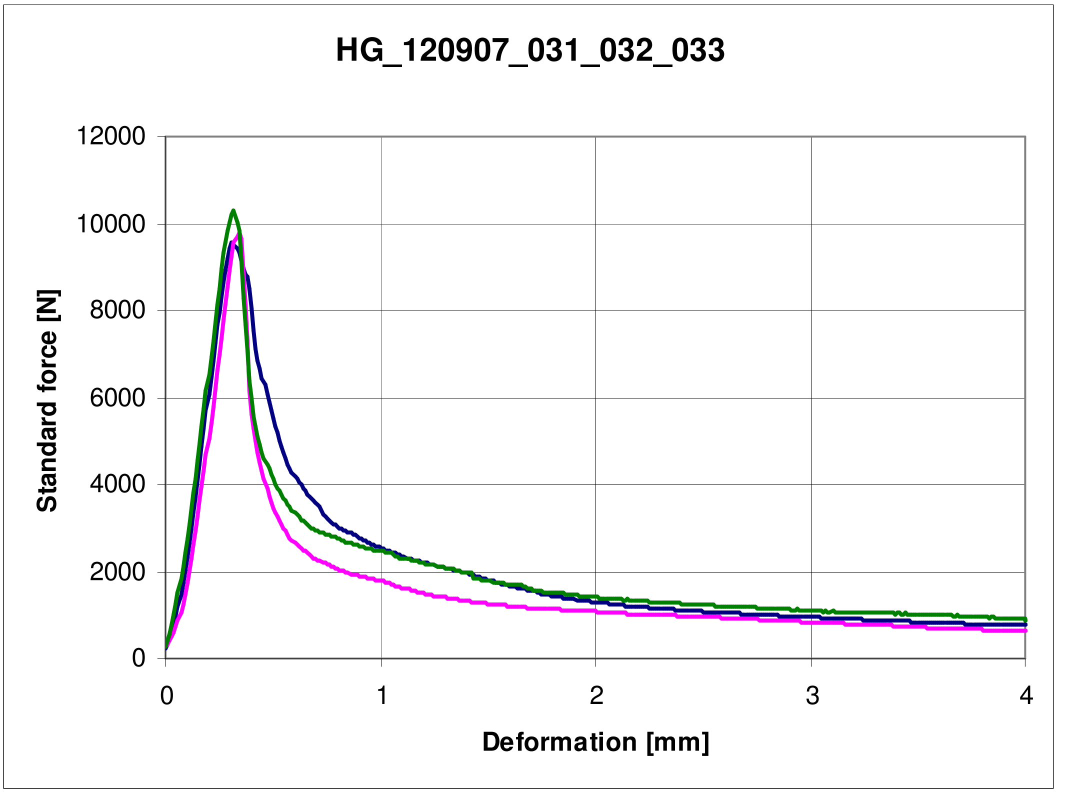
Details of the fibre

type:	fibrillated
section:	flat
length:	19 mm
diameter:	-
weight:	-
number in 1 kg:	-
dosage:	1 kg/m^3
volume%:	-

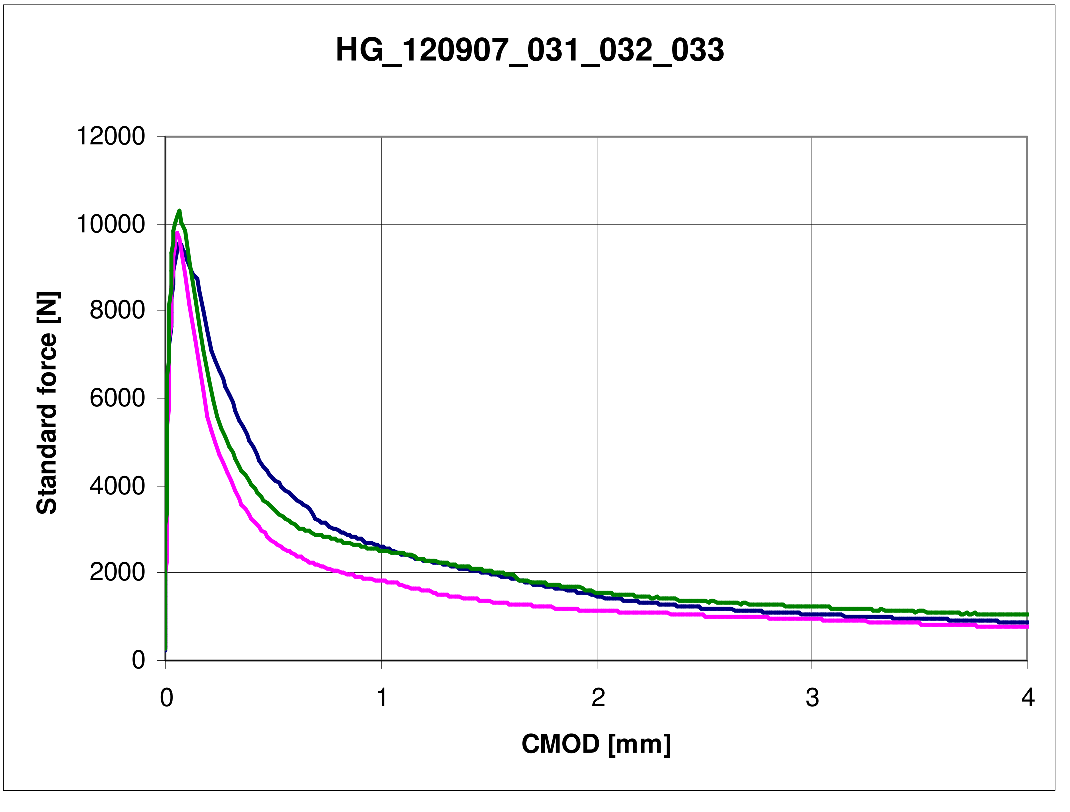
Notes

The fibre at the dosage above mixed well, the fresh fibre reinforced concrete was homogenous and easy to compact.

4.12.1. Load-deflection diagram



4.12.2. Load-CMOD diagram



4.12.3. Photos

120907_031

120907_032

120907_033

4.13. MIKRO2 (fibrillated) – dosage 1 kg

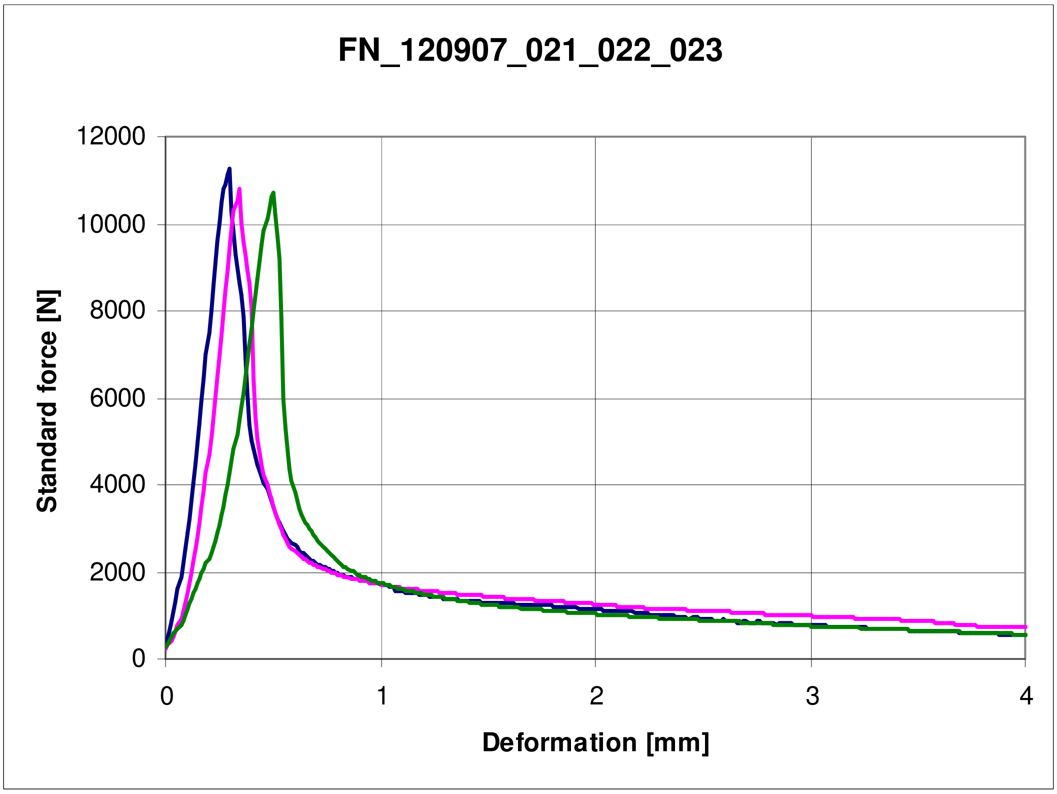
Details of the fibre

type:	fibrillated
section:	flat
length:	19 mm
diameter:	-
weight:	-
number in 1 kg:	-
dosage:	1 kg/m^3
volume%:	-

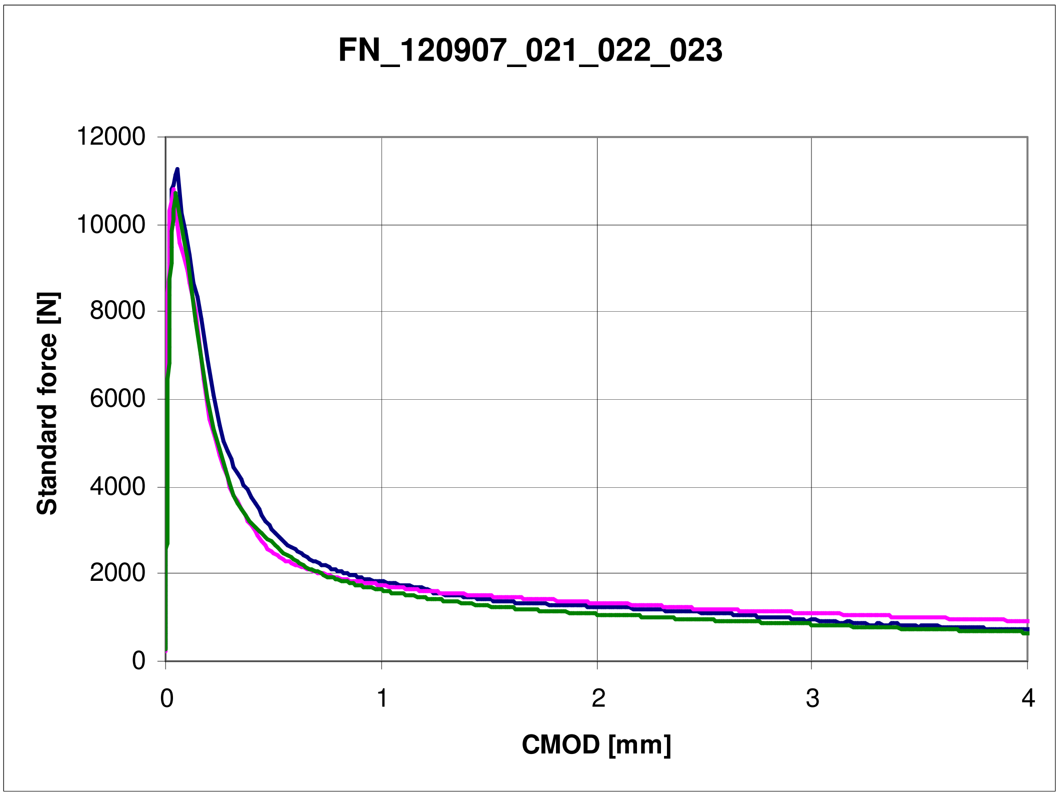
Notes

The fibre at the dosage above mixed well, the fresh fibre reinforced concrete was homogenous and easy to compact.

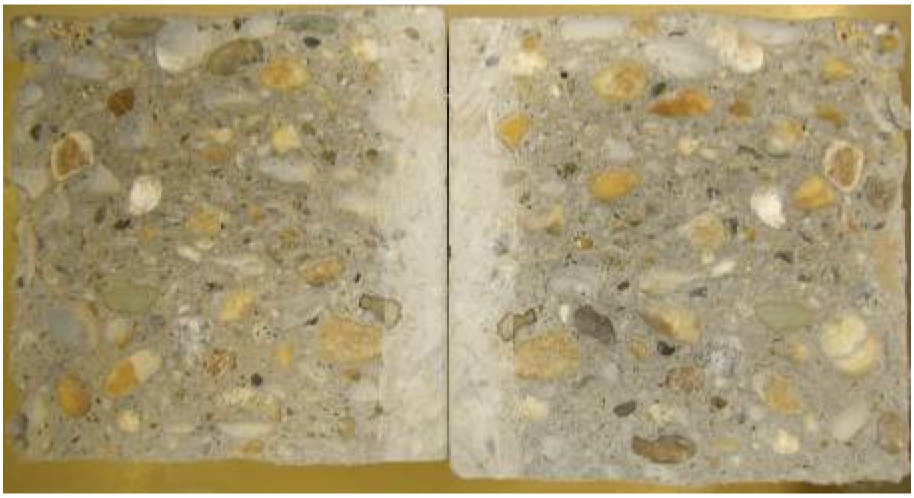
4.13.1. Load-deflection diagram



4.13.2. Load-CMOD diagram



4.13.3. Photos



120907_022

120907_023

4.14. MIKRO3 (mono) – dosage 1 kg

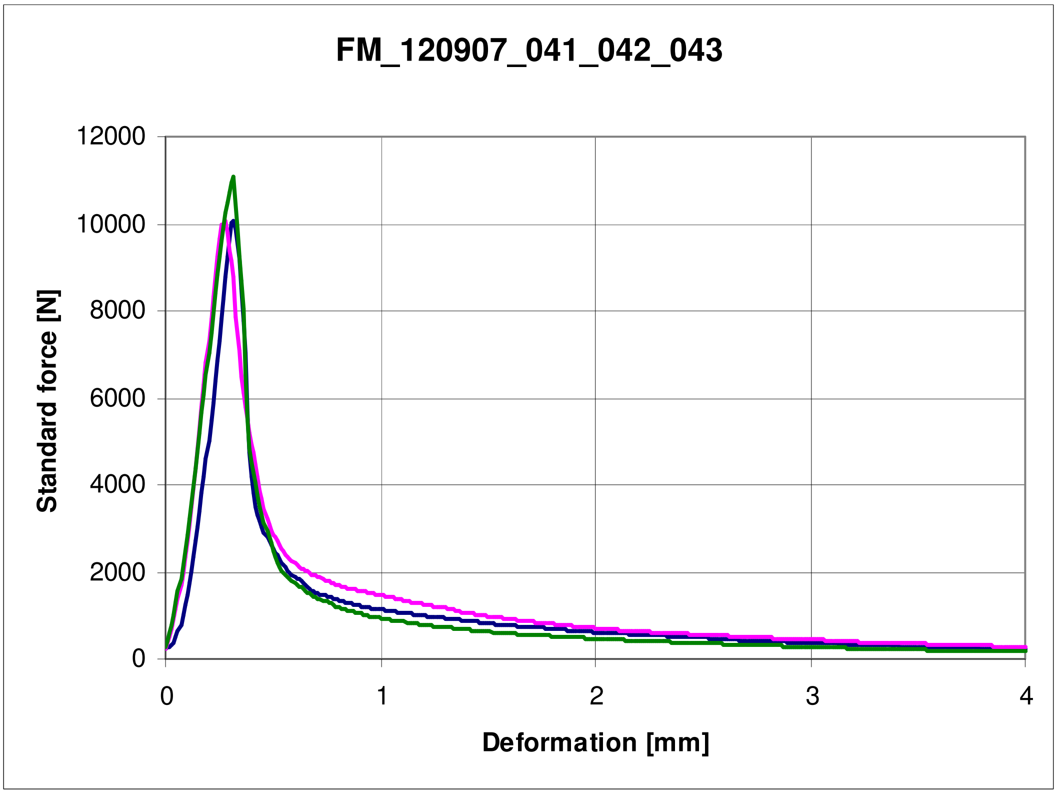
Details of the fibre

type:	mono fibre
section:	circle
length:	10 mm
diameter:	-
weight:	-
number in 1 kg:	-
dosage:	1 kg/m^3
volume%:	-

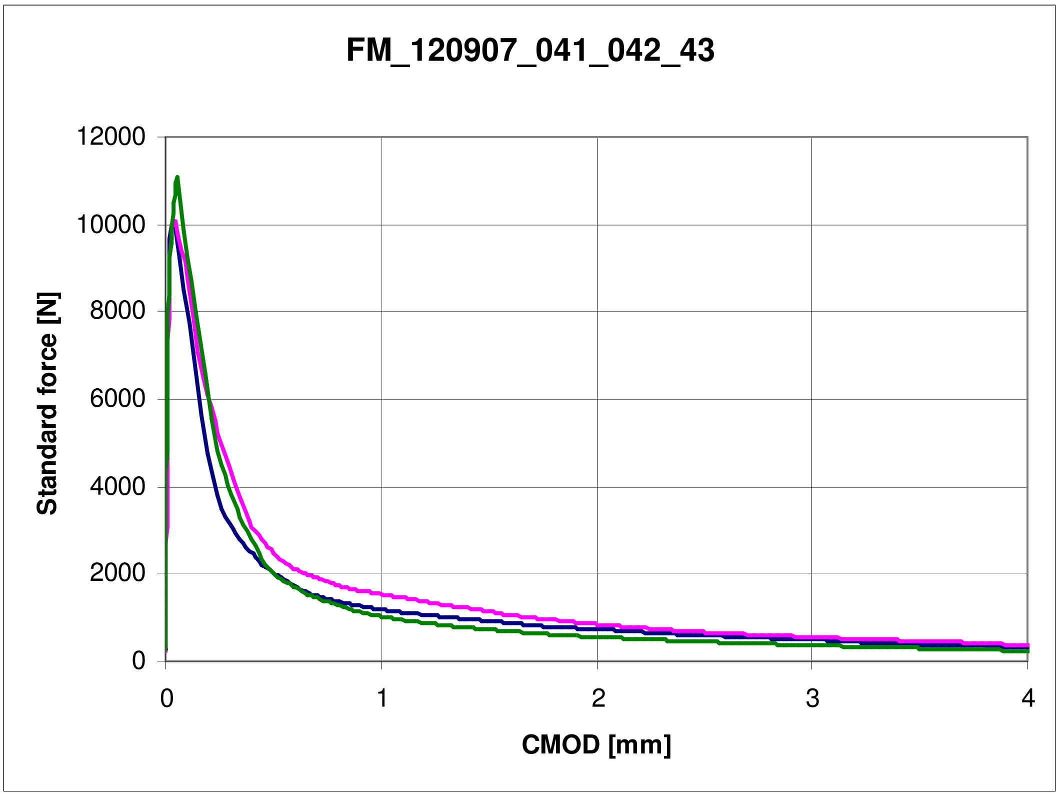
Notes

The fibre at the dosage above mixed well, the fresh fibre reinforced concrete was homogenous and easy to compact.

4.14.1. Load-deflection diagram



4.14.2. Load-CMOD diagram



4.14.3. Photos

120907_041

120907_042

120907_043

5. Conclusions
5.1. Minimal fibre dosage

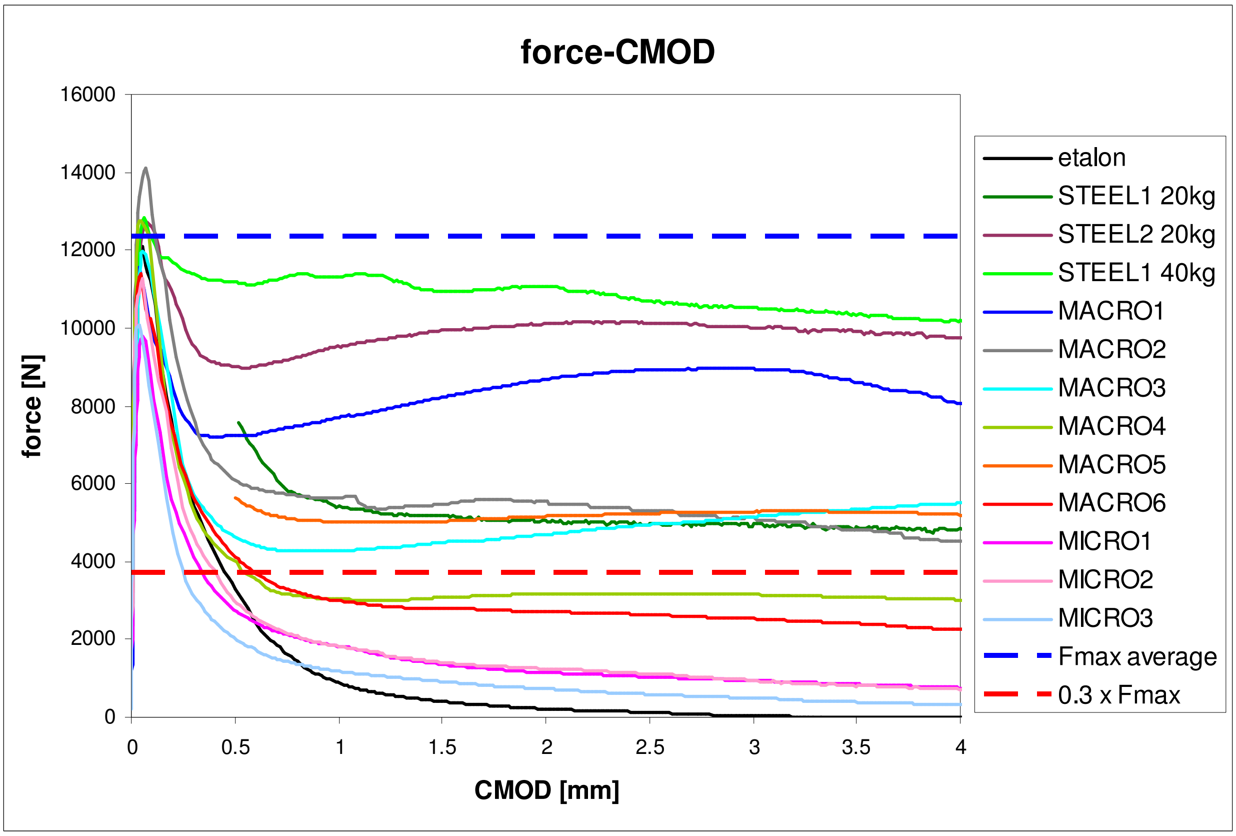
There are two main criterion in the guidelines for the minimal dosage of fibre:
- necessary dosage by geometry
- necessary dosage by the residual stress.

The **necessary dosage by geometry** is based on the proviso that the fibres must be overlapping each other, i.e. no section could be formed without crossing fibres present.

It is important to highlight here, that the crack will appear at the notched, weakened section for the 3 point bending test, so only the fibres that are crossing this section are significant. The Austrian guideline (Richtlinie Faserbeton, 2008) and others recommend a 4 point bending test where the moment is constant between the loading points, so the weakest section will crack first. Both of them have advantages and disadvantages, but the CMOD could be measured only using the 3 point bending test.

The mixing properties of the fibres are also important. If the test is to be representative, there needs to be a homogenous mix of fibres within the whole of the beam so as to ensure the correct fibre crossing at the notched section.

The **residual stress** is characterized by the R_{e3} number, so the guidelines give the minimum values of this. TR34 gives a minimum 30% of R_{e3} number, and any FRC that has a lower value than this should be considered as plain concrete.



picture 4: summarized results of the beam tests

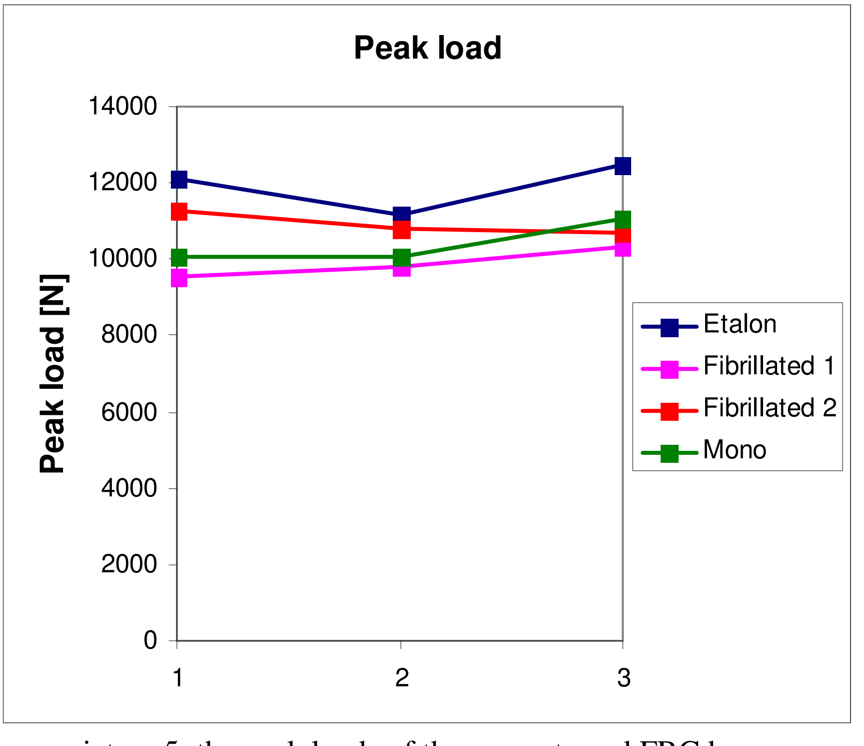
We took all the FRC beam results into one diagram (picture 4). It is important to say, that we used the average for this purpose, but for classification the standard deviation should be considered.
The blue dashed line shows the average of the plain concrete flexural strength, the red dashed line shows 30% of this. The fibres that have results above this red line are suitable for industrial floors. The following fibres didn't meet this criterion: MACRO4, MACRO6 and MICRO fibres.

5.2. Effects of the micro fibres

There isn't any common use of the world micro and macro in Hungary, and many engineers and end users don't even know the difference between the two types. For this reason, most people overestimate the effect of the micro fibre, or underestimate the effects of macro.

The micro, e.g. fibrillated and mono fibres have no effect on the residual strength, the R_{e3} number is well below 30% (see picture 4), so the benefits they provide are strictly limited to limiting early age cracks due to plastic shrinkage. We didn't do any further research for this, as it is difficult to quantify, although the Austrian guideline gives a method for this.

However, having stated the foregoing and following the train of thought that all the macro cracks start off as micro ones, it might be thought that the use of micro fibres might increase the flexural strength of FRC, by force of reducing the number of initial micro cracks in the concrete. But this theoretical assumption is not supported by the experimental results, and indeed the micro fibres make the peak load lower when compared to plain concrete beams.



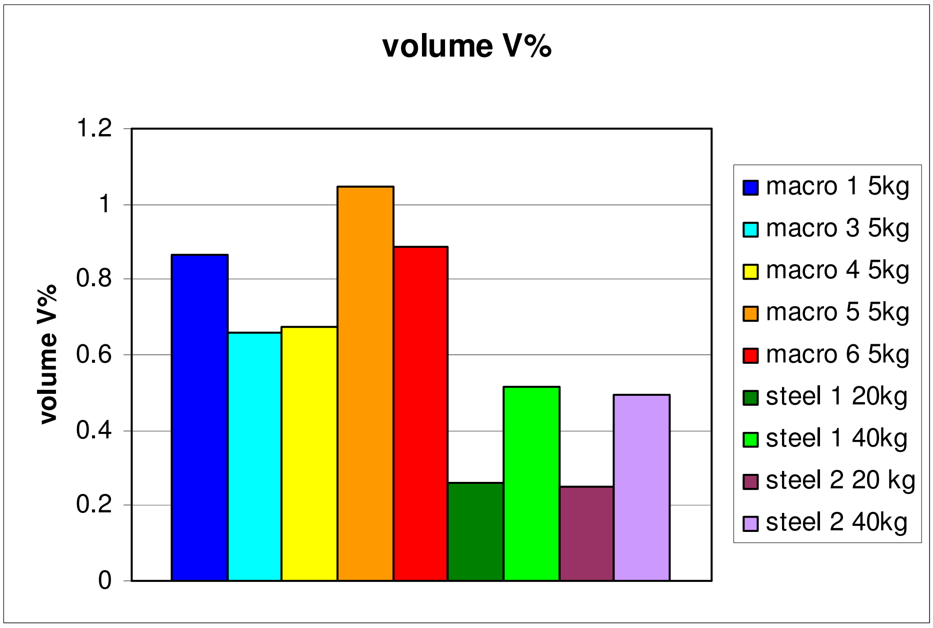
picture 5: the peak loads of the concrete and FRC beams

The results of the picture 5 could give rise to further research, but we can draw the conclusion: micro fibres could be used for structures where the aesthetic appearance of the concrete surface is important, and where the static load won't be significant in the future. However, this is not recommended in industrial floors, where the concrete structure is preliminary designed for static loads, and the aesthetic appearance is only secondary.

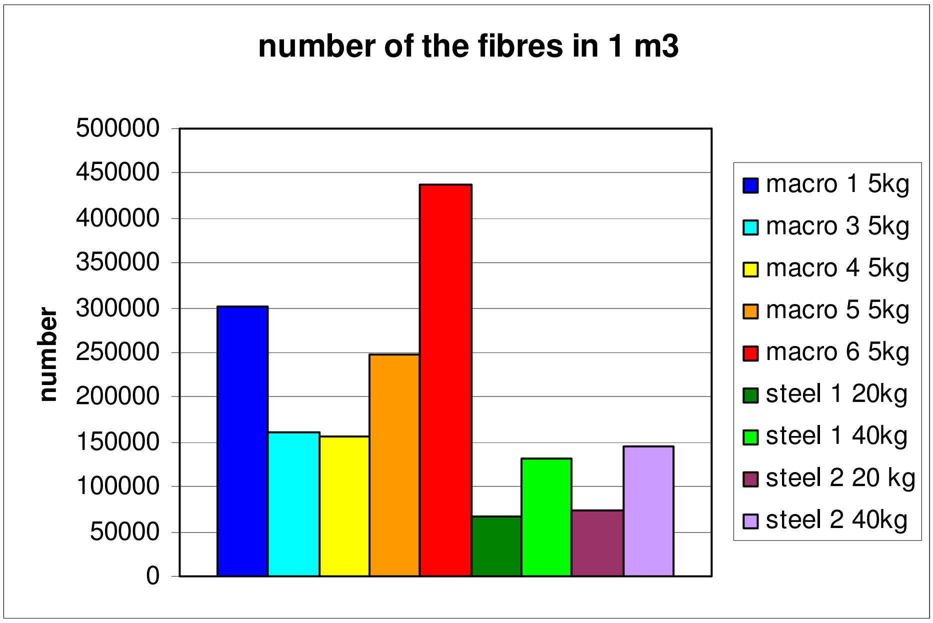
5.3. What kind of fibre do we choose?

The characterisation and differentiation of FRC is preliminary according to its R_{e3} number. For shotcrete the EFNARC or similar panel tests could give a result in Joules. Either method is adequate for comparison purposes.

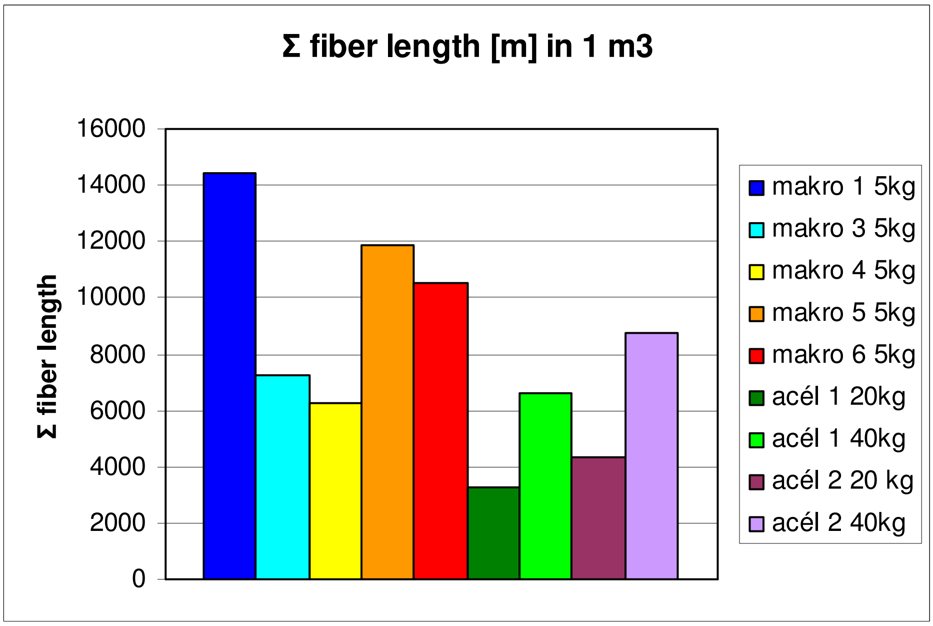
Another characterisation of the dosage of the fibre is its weight in 1 m^3 concrete. While the steel weight is more or less the same, we can find significant differences between the weight of synthetic materials. Therefore, comparing steel and synthetic fibres on this basis is not helpful. A more correct comparison is the volume%, the number of the fibres or the overall length in 1 m^3 concrete.



picture 6: the volume% of the fibres



picture 7: number of the fibres



picture 8: overall length of the fibres

These comparative diagrams clearly show that while the same dosage (5 kg/m^3) of macro fibre is added to all types, the volume%, fibre count, overall length values were different. All these diagrams, for both the measured values clearly show that fibres are not comparable by weight alone, i.e. **one type of fibre cannot be replaced with the other without material testing!**

References

Vandewalle, L., et al. (2002) *„Test and design methods for steel fibre reinforced concrete - Final"*, Materials and Structures, 35(253)

The Concrete Society UK (2003) *„Technical Report No. 34"*, The Concrete Society UK

Japan Society of Civil Engineers (1985) *„Method of test for flexural strength and flexural toughness of SFRC"*, Standard JSCE SF-4

Österreichusche Vereinigung für Beton- und Bautechnik (2008), *„Richtlinie Faserbeton, Ausgabe Juli 2008"*

Annex A

	A	B	C	D	E	F	G	H	I	J	K
1	**FVM-v120504**		Nr / Minta azon							Liter	Víztar-
2	ipari padlóbeton									22	talom
3	MAPEI - BME szálbeton vizsgálat			%	kg/m^3	g/cm^3	Ft/kg	Liter	Ft	g	%
4			CEM 525			3,12	0,000	0			
5			EM II/A-S 42,5 N Holcim Rohoznik (SK)	100,0	**325**	3,10	0,000	105	0	7 150	
6			CEM 325			3,10	0,000	0			
7			k_v/c_v/(c+k*p)_v/c+PZ500	0,4	0,492	0,492	0,492		MSZ 4798 össz CEM		325
8			víz		**160**	1,00	0,000	160		3 307	
9			Filter Pernye			2,10	0,000	0			
10			mikroszilika Mapeplast SF			0,60	0,000	0			
11			LB Tatabánya tech maradék			2,70	0,000	0			
12			Bazalt Liszt			2,80	0,000	0			
13	130	28,3	0/4 Yorks	42	**799**	2,64	0,000	302	0	17 743	1,00
14	130	28,3	4/8 Yorks	18	**342**	2,64	0,000	130	0	7 566	0,50
15	200	43,5	8/16 Yorks	22	**418**	2,64	0,000	158	0	9 202	
16			16/24 Yorks	18	**342**	2,64	0,000	130	0	7 529	
17						2,64	0,000	0			
18						2,64	0,000	0			
19						2,64	0,000	0			
20						2,64	0,000	0			
21	kg	%	Terv . Légtart.	1,5				15,0		42 040	1
22	**460**	**100,0**	Össz Adalék.	100	1 901		1m^3=	1 000		1	v / c
23	váz rekonstrukció		Terv. Testsûr.		2 386	v / c				2	f / c
24			sr3	0,400	**1,30**	1,07	0,0	1,2	0	28,60	26,73
25			0								
26			0								
27			0								
28			Adalékszer érték	0,400	1,30			1,2	0	28,6	26,7
29			Beton érték						0		
30				%	kg/m^3	g/cm^3	Ft/kg	Liter	Ft	g/kg	ml/Lit

KEVv8

MAPEI

Beton keverék számítás

beton jele
MSZ 4798 szerint **C 30/37-XC4-XD2-XF1-XA1-XV2(H)-24-F3-CEM 42,5 ipari padlóbeton**

MAPEI Betonlabor
2038 Sóskút, Külterület 063/7
Tel/Fax 23/501-670, 23/560-522

Üzem / Munkahely: MAPEI Betonlabor
Projekt / Szerkezet: szálerősítéses ipari padlóbeton

Recept azonosító:
Adalékgörbe azon: 0,00
Különl. Tulajdon.: ipari padlóbeton

Alkalmazhatóság MSZ 4798-1:2004

Környezeti osztályok

X0H	XC	XD	XS	XF	XFH	XA	XKH	XVH	vízzáró	fagyálló	pumpálható	agresszív e.	kopásálló
v	3	2	1	1	2	1	1	1	X	X		3	

			Tervezett:	Előírt jellem.	MSZ 4798
Szilárdsági osztály	C	N/mm2	30	40	30/37
Szemnagyság max	Dmax	mm	24		24
Konzisztencia			K	Szüks. Rm	F3
Levegő tartalom		%	1,5	44	1,5
Cementtartalom		kg	325		CEM 42,5
Testsűrűség		kg/m3	2388	Várható Rm	2388
v/c			0,492	44	0,492
Eltarthatóság		óra	1		1

Vízzáró / Fagyálló / Kopásálló XC4-XD2-XF1-XA1-XV2(H)

ADALÉKANYAGOK

Fajta	Gyártó
OH 0-4	LB Yorks
OK 4-8	LB Yorks
OK 8-16	LB Yorks
OK 16-24	LB Yorks
0	0
0	0

ALAPANYAGOK

Cement gyártó	Holcim Rohoznik
Fajta	CEM II/A-S 42,5 N
Kiegészítő anyag gyártó	
Fajta	
Adalékszer gyártó	MAPEI
Fajta	Dynamon SR 3
Főhatás	HRWR+SRA
Vízmegtakarítás	

TÉRFOGATSZÁMÍTÁS

		kg/m3	Sűrűség:	Térfogat l/m3
Szám. víztartalom		160	1,00	160
Cementtartalom		325	3,10	105
Kieg.anyag tart.		0	1,00	0
Levegőtartalom				15
Szám. ada. tart		1901	2,64	720
Adalékszer 1.%	0,40	1,30	1,07	1,21
Adalékszer 2.%	0,00	0,00	1,00	0,00
Adalékszer 3.%	0,00	0,00	1,00	0,00
Összesen :		2387		1001

ADALÉKANYAG KEVERÉK SZÁMITÁS:

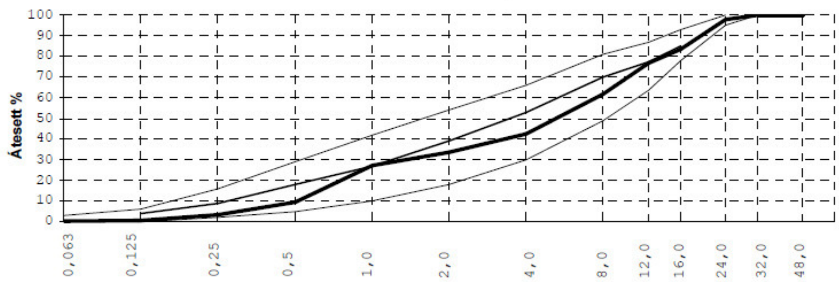
Adalék frakció	Rész %	Térfogat liter	Sűrűség	Tömeg kg/m3
OH 0-4	42 %	302	2,64	799
OK 4-8	18 %	130	2,64	342
OK 8-16	22 %	158	2,64	418
OK 16-24	18 %	130	2,64	342
0	0 %	0	2,64	0
0	0 %	0	2,64	0
Összesen :	100 %	720	2,64	1901

FINOMRÉSZ TARTALOM

	%	kg/m3
0,25 mm alatti rész	3,41	65
Cement		325
Kiegészítő anyag		0
Összesen :		390

PÉPTARTALOM

	liter/m3	Pépigény:	Pépkülönbözet:
Víztartalom	160		
Cement tartalom	105		
Kiegészítő anyag tartalom	0		
Összesen :	265	224	+ 40 l/m3



Szitaméret (mm)

m_A = 7,13
m_B = 5,96
m_C = 5,1

Adalékgörbe azonosító:

m = 6,38
U = 19,57
f = 0,0 %

1 m3 beton tervezett összetétele:

			rész %	térfogat l/m3	tömeg kg/m3
Cement :		CEM II/A-S 42,5 N		105	**325**
Víz :		Összes víz		160	**160**
Kiegészítő anyag :				0	**0**
Adalékanyag :	1	OH 0-4	42 %	302	**799**
	2	OK 4-8	18 %	130	**342**
	3	OK 8-16	22 %	158	**418**
	4	OK 16-24	18 %	130	**342**
	5	0	0 %	0	**0**
	6	0	0 %	0	**0**
Σ adalék			100 %	720	1901
Levegőtartalom .			1,50 %	15	
Adalékszer 1 :		Dynamon SR 3	0,40 %	1,21	**1,30**
Adalékszer 2 :			0,00 %	0,00	0,00
Adalékszer 3 :			0,00 %	0,00	0,00
Σ frissbeton				1001	**2388**

Dátum **2011.07.07**

Aláírás

Ellenőrizte

Jóváhagyta

Engedélyezte

Technológiai utasítás: