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# Comparison of Properties of Concretes with Different Types and Dosages of Fibers

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## Abstract

Concretes with PP fibers 12 mm, construction polymer fibers 25 mm, 3D steel fibers 25 mm, and steel microfibers 12 mm were prepared in dosages 0.5 and 1%. The mechanical properties (compressive strength, bending strength, fracture properties, and modulus elasticity) and the frost resistance of these concretes were tested and they are discussed. The behavior of these concretes is also discussed using graphs load vs. deflection. As bad results of frost resistance are sometimes recorded for concrete with fibers, this property is also evaluated. As was expected, mechanical properties are enhanced with the addition of suitable fibers. Frost resistance is usually comparative with concrete without fibers, but in the case of concrete with 1% of steel fibers, it is reduced.

**Keywords:** fiber-reinforced concrete, high-performance concrete, fibers, fracture, frost resistance

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## 1. Introduction

Nowadays, fiber-reinforced concrete (FRC) is increasingly used for different applications—pavements, industrial floors, or high-performance concrete applications. The applications in high-performance concrete elements and structures are especially important because structures from HPC are subtle and there is not enough space for flexural reinforcements—stirrups—inside them. The question is which type of fibers and which dosage to apply. Although there has been some good experience with synthetic structural fibers [1], steel fibers are most widely used in these applications. The effect of the steel fiber is affected especially by the shape of the fibers; a more detailed study was performed, for example, by Pajak and Ponikiewski [2]. Corrugated or hooked fibers show the best effect. The next question is what the correct testing method is for the estimate of the fiber effect. Usually, prisms with the cross-section  $150 \times 150$

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mm are recommended [4]. But the subtle constructions have smaller dimensions. Yhang et al. [3] used  $100 \times 100$  mm prisms for the testing of FRC with microwires. In this paper, prisms with the cross-section  $80 \times 80$  mm are used because they correspond to produced element dimensions [1, 5]. In Ref. [4], a four-point bending test is recommended on an unnotched prism whose volume is nearly 16 L. In this paper, notched prisms  $80 \times 80 \times 480$  mm (volume 3.1 L) are used with the central notch and they are tested in a three-point bending. As expected, the results are different from that of Ref. [4] and not objective from the point of view of concrete properties, but they are more similar to a practical situation from the point of view of the arrangement of fibers.

The structural design of these subtle constructions is often very difficult and the best way to evaluate the properties are tests in a 1:1 scale, see also Refs. [5, 6].

There are different kinds of fibers for different purposes. For example, steel wires or structural synthetic fibers are designed for similar purposes, but it is clear that their performance will be different. The possibility to substitute different types of fibers with other ones and optimize their dosage was the main purpose of this paper.

## 2. Experimental procedure

### 2.1. Materials

The concrete was designed as a high-performance concrete for class C70/85 XF1 (see EN 206). Ordinary Portland cement CEM I 42.5 R produced in cement plant Mokra was used. Metakaolin was added for enhancing the workability of the mixture and also for enhancing strengths. Commercial polycarboxylether superplasticizer, drinkable water, and commonly produced aggregates—sand 0/4 and crushed granite (Litice nad Orlici quarry)—were also used. Water to binder ratio  $w/(c+m) = 0.27$ .

Different types of fibers were used—polypropylene 12 mm long fibers in dosage  $0.5\%_{vol}$ , so-called structural synthetic polymer 25 mm long fibers— $0.5$  and  $1.0\%_{vol}$ , 3D steel fibers 30 mm long  $0.5$ , and  $1.0\%_{vol}$  and steel microfibers 13 mm long  $0.25$  and  $0.5\%_{vol}$ . Properties of these fibers are presented in **Table 1**.

		Length	Diameter	Tensile strength	Modulus of elasticity
Designation in this paper		[mm]	[mm]	[MPa]	[GPa]
PP micro fibers	PP	12	0.09	460	3.5
Structural fibers	S	25	1	650	5
Steel 3D fibers	D	30	0.54	1200	
Steel Microfibers	M	13	0.21	2750	200

**Table 1.** Type and properties of used fibers.

Concretes were mixed in a laboratory mixer; the volume of each batch was 30 L. Workability was measured using reverse Abrams cone. After mixing the concrete was placed into steel molds. After demolding at the age of 22–24 hours, specimens were stored in water  $t = (20 \pm 2)^\circ\text{C}$ .

## 2.2. Specimens

Cubes 100 mm were used for compressive strengths tests at the age of 28 days. Prisms  $80 \times 80 \times 480$  mm were made for the testing of fracture properties and for the testing of frost resistance. A notch to depth cca 28 mm (1/3 of high) was cut into the beams 220 mm from the one end of the beam at the age of 28 days. Fracture tests in accordance with the Karihaloo and Nallathambi effective crack model [7] were performed on the notched beam (span 400 mm). The fracture toughness  $K_{IC}$  is the main result of these tests. Toughness  $G_c$  was also computed. Fracture work  $W_F$  was computed from the load-deflection curve in accordance with RILEM recommendation [8, 9]. The modulus of elasticity in a three-point bending on notched beam  $E$  as well as the modulus of rupture  $f_r$  (flexural strength on the notched beam) are the partial results of these tests. After the fracture test, a part of the broken beam, whose length is approximately 260 mm, was used for the test of flexural strength  $f_b$  (span 220 mm). Other beams  $80 \times 80 \times 480$  mm were exposed to 125 freezing and thawing cycles (FT-cycles) in accordance with Czech norm CSN 73 1322—frost resistance of concrete. One cycle represents 4 hours in the freezer at the temperature  $-20^\circ\text{C}$  and 2 hours in water  $+20^\circ\text{C}$ . After the cycles, values of flexural strength, modulus of rupture, and modulus of elasticity were measured and compared with the values at the age of 28 days. Activity indexes  $I_b$ ,  $I_r$ , and  $I_E$  were calculated as a ratio value of *values comparative beams/values of frosted beams*.

## 3. Results and discussion

### 3.1. Mechanical properties

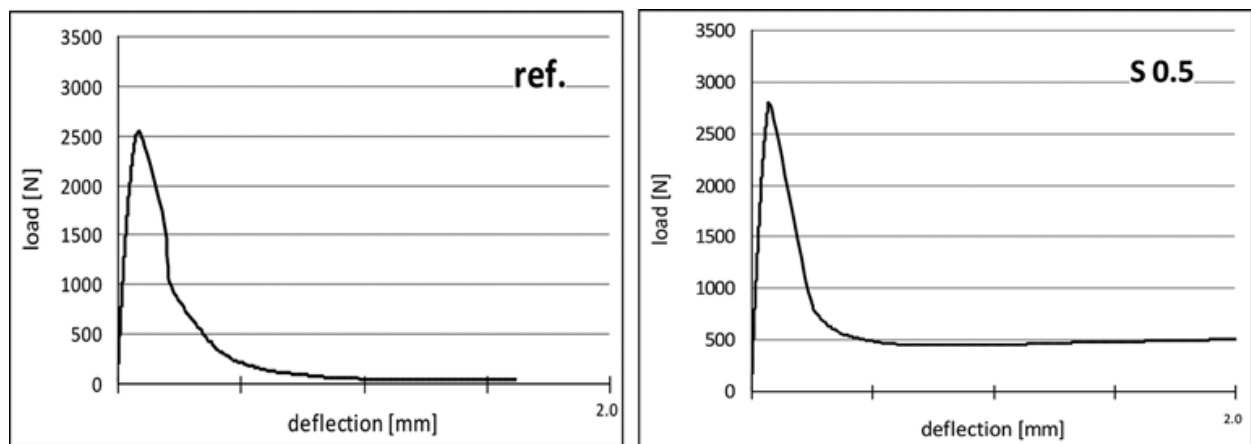
The recorded results are shown in **Table 2**. The first property is workability. It is evident that the concrete which was obtained with the cone flow cca 350 mm was completely different from the originally very flowable, self-compacting concrete with the cone flow 850 mm. This was the case of PP fibers, but the dosage of these fibers was five times higher than normally recommended. This experiment was performed for the comparison and the information about the impact on workability in concretes with enhanced fire resistance, thanks to PP application. In all these cases, the workability can be regulated with a higher dosage of superplasticizers but this method was not used in this case.

The compressive strength  $f_c$  is the highest for the content of fiber 0.5% or 0.25 for M-fibers. These concretes are well compacted and fibers can work well. The value of  $f_c$  is not affected by the fiber materials; all structural fibers show similar results in dosage 0.5%.

The flexural strengths  $f_b$  and  $f_r$  show different courses. The differences are demonstrated in **Figures 1–3**. In **Figure 1**, the load-deflection curve for the reference concrete and the concrete with 0.5% of S-fibers is shown. The maximum value of load is nearly the same, but the postpeak regime is different—there is some residual strength for FRC. The load-deflection

		ref.	PP 0.5	S 0.5	S 1.0	D 0.5	D 1.0	M 0.25	M 0.5
<b>cone f. [mm]</b>		<b>850</b>	<b>350</b>	<b>530</b>	<b>340</b>	<b>790</b>	<b>610</b>	<b>470</b>	<b>360</b>
$f_c$	[MPa]	93.7	89.1	102.5	95.0	105.2	95.1	101.4	98.4
		±2.8	±3.3	±2.2	±3.1	±1.7	±15.5	±1.5	±7.5
$f_b$	[MPa]	7.4	7.6	9.45	8.4	10.4	12.5	8.7	11.3
		±0.6	±0.2	±0.4	±0.7	±0.9	±0.4	±0.5	±0.7
$f_r$	[MPa]	6.8	7.0	7.8	7.0	7.9	8.6	7.0	9.4
		±0.3	±0.3	±0.1	±0.4	±0.2	±0.1	±0.2	±0.6
$E$	[GPa]	39.4	36.9	39.8	37.3	38.6	41.0	36.2	37.8
		±1.1	±0.5	±0.9	±1.4	±2.1	±0.8	±0.9	±1.1
$K_{IC}$	[MPam <sup>1/2</sup> ]	1.62	1.65	1.58	1.54	1.68	2.26	1.78	1.92
		±0.1	±0.2	±0.1	±0.1	±0.11	±0.8	±0.32	±0.25
$G_c$	[Jm <sup>-2</sup> ]	67.6	75	63	63	74	125	92	100
		±6	±18	±7	±5	±7	±10	±37	±30
$W_F$	[Jm <sup>-2</sup> ]	141	231	620	1215	5025		193	332
		±9	±26	±100	±100	±680		±10	±95
$I_b$	[%]	100	96	84	92	82	61	81	76
$I_r$	[%]	89	91	91	94	95	120	80	87
$I_E$	[%]	104	102	89	86	104	84	86	88

**Table 2.** Workability, mechanical properties, and indexes of frost resistance of concretes with fibers.



**Figure 1.** Typical load-deflection curves of concrete "ref" and S 0.5.

curve for the content of 1% S-fibers is very similar, only the residual strength is higher—it does not show here. The highest values of load are reached for steel fibers, especially for the steel fibers with a special shape—hooked ends—3D fibers (see **Figure 2**). These fibers hold in the matrix very well and they enhance  $f_b$  and  $f_r$ . D-fibers are long enough, which means that the

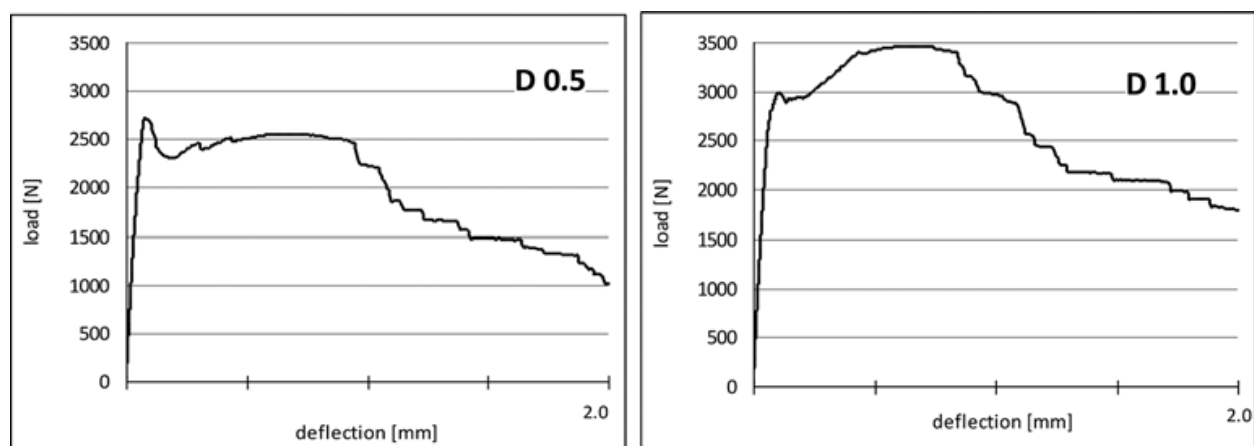


Figure 2. Typical load-deflection curves of concrete D 0.5 and D 1.0.

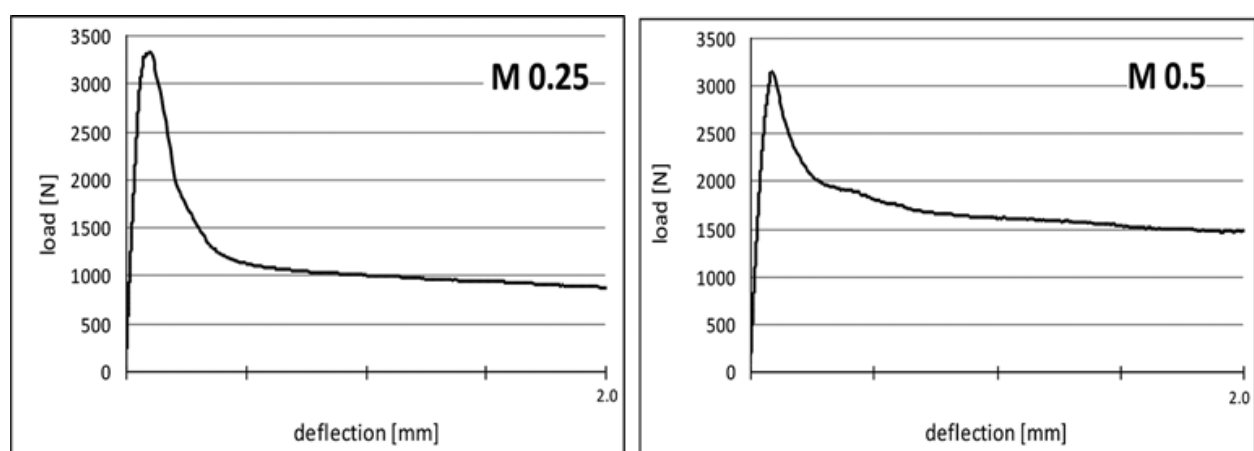


Figure 3. Typical load-deflection curves of concrete M 0.25 and M 0.5.

concrete shows a significant residual strength after the first peak. The results for 0.5 and 1% differ especially in the course curve after the first peak. These results are very similar to those of Ref. [2]. Micro steel fibers (**Figure 3**) work well for the big amount; the improvement of  $f_b$  and  $f_r$  is the most conspicuous and the dosage of fibers is 1/2 of the previous—only 0.25 and 0.5%, but they are short and they are pulled out early.

The values of the modulus of elasticity are nearly the same—with respect to the standard deviation. Also fracture toughness  $K_{IC}$  and toughness  $G_c$  is similar for all of the mixtures. The load from the first peak was considered the value of the maximum recorded load. The effect of fibers on the improvement of concrete without microcracks is considered in this case.

### 3.2. Frost resistance

The indexes of frost resistance are shown in **Figure 4**. The first columns are the indexes in terms of flexural strength  $f_b$ , the second ones in terms of flexural strengths on notched prisms  $f_r$  and the third ones in terms of the modulus of elasticity  $E$  measured in a three-point bending on

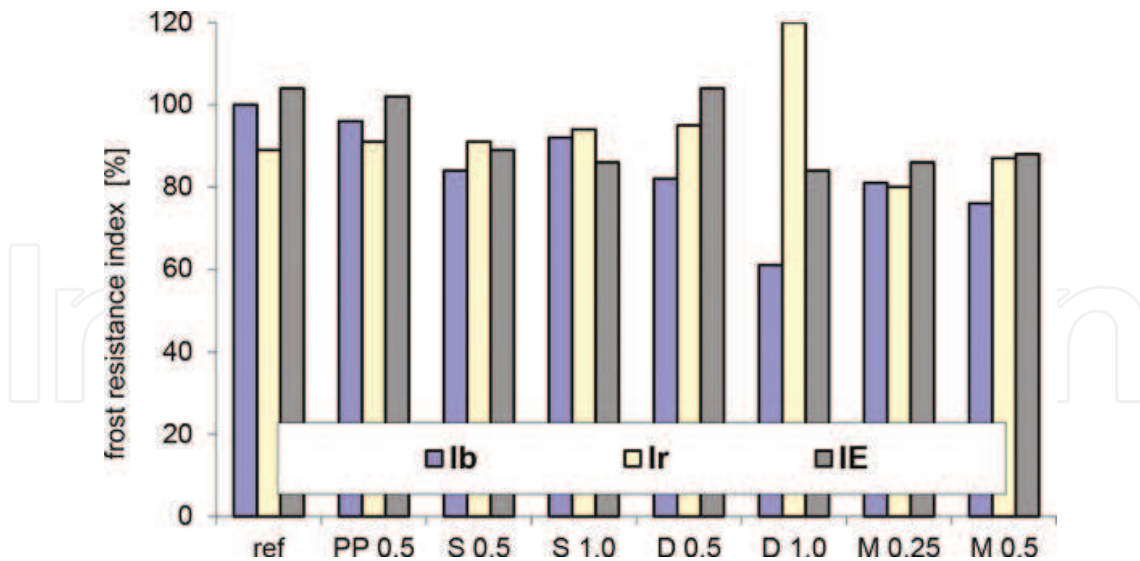


Figure 4. Frost resistance indexes  $I_b$ ,  $I_r$  and  $I_E$  expressed in terms of  $f_b$ ,  $f_r$  and  $E$ .

prisms with a central notch. The  $f_b$  is affected especially by the properties of the surface layer while the  $f_r$  is affected by the properties of the central regions of the cross-section [9].

The best values are recorded for the concrete without fibers. All FRC fulfill the requirements of CSN 73 1322 –  $I > 75\%$ , except the concrete with 1% of D-fibers in terms of  $f_b$ . Concrete M 0.5 shows  $I_b$  on the boundary of acceptable value. The experience proves that FRC with wires has worse frost resistance. In terms of  $f_r$  and  $E$  the frost resistance is good. This probably means that the surface layer of the concrete is affected by the water which penetrates around the wires into the concrete and freezes later. This result—significant reduction of frost resistance—can be a consequence of the small size of the specimen, but it is especially important for the subtle or thin construction from FRC.

## 4. Conclusions

From the above-mentioned results, some general conclusions can be drawn:

1. Fire-reinforced concretes show similar or higher compressive strength in comparison with reference concrete.
2. All fibers enhance flexural strength, and the most conspicuous increase is recorded for steel fibers.
3. All fibers affect the postpeak course of the load-deflection diagram. Only steel fibers make it possible to reach a higher load after the first peak. But in this case, the microcracks are developed and bridged with fibers. These fibers are not protected by concrete and they can be destroyed by the attack of some aggressive media. Durability of the concrete can be a problem.



4. The frost resistance of concretes with steel fibers can be reduced—probably thanks to the penetration of water along the fibers. This is especially important for the subtle cross-sections. This can also be one of the reasons why to perform tests using small size specimens, too.
5. On the basis of the published results, the concrete with 0.5 of D-fibers was selected as the best possibility for the production of subtle concrete elements. Tests in a 1:1 scale confirmed rightness of this choice [6].

This investigation is being continued with the target to compare the results recorded in small size specimens with those of preliminary norm requirements [4].

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