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CIVIL AND ENVIRONMENTAL ENGINEERING REPORTS

E-ISSN 2450-8594 CEER 2018; 28 (4): 138-148
DOI: 10.2478/ceer-2018-0057
Original Research Article

INFLUENCE OF STEEL AND POLYPROPYLENE FIBERS ADDITION ON SELECTED PROPERTIES OF FINE-GRAINED CONCRETE

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Abstract

The article presents results of laboratory tests of selected mechanical and physical properties of fine-grained fiber concrete. Tests were conducted on samples with a different degree of reinforcement made on the basis of steel and polypropylene fibers. For the designed concrete mixtures and prepared samples, slump class, shrinkage, compressive and bending strength and water tightness were determined.

Keywords: fibers, fine-grained concrete, laboratory tests

1. INTRODUCTION

The addition of fibers into concrete causes an increase in the material's ductility, an increase in crack energy, reduces scratches and significantly improves strength parameters (compressive and tensile strength). Good results are achieved through combining the addition of steel fibers of different sizes [1], that is micro-fibers (the exemplary order of magnitude: length 9 mm, diameter 0.17 mm) and macro-fibers (the exemplary order of magnitude: length 60 mm, diameter 1.0 mm). Thanks to the cooperation of both types of fibers,

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compressive and tensile strengths increase and the behavior after scratching improves [3]. Micro-fibers are to prevent the propagation of micro-cracks, stopping their development and not to allow them to transform into cracks which endanger the steadiness of the material structure. At the same time, macro-fibers play the same role, but at a higher size scale. The positive influence of the addition of fibers is the effect of lowering the stress concentration. They carry loads through discontinuities in the material structure, such as cracks and fractures. Fibers' parameters which significantly influence their effectiveness include: length, diameter, tensile strength and shape. Waved fibers or those with hooked ends bring better results than the application of straight fibers even in greater numbers [2]. The slenderness of such an addition is also important. It should not be lower than 50. The alternative to steel fibers can be plastic fibers. They are characterized by resistance to corrosion and their addition to a small extent increases concrete volume weight. A significant disadvantage of this type of fibers is low resistance to high temperatures. Fibers is an essential addition to ultra-high-strength concrete such as reactive powder concrete (RPC) [1]. It is fine-grained concrete in which the most important factor causing high strength is a large reduction in crack formation caused by, for example, load or shrinkage, by reducing the maximum grain size aggregate ≤ 600 μm and degrading them to micro. Table 1shows an example of a recipe for such a concrete [4].

Table 1. An example of RPC concrete composition

Component	Volume [kg/m^3]	Mass percentage [%]
Cement	705	28.20
Silica fume	230	9.20
Crushed quartz ≤ 200 μm	210	8.40
Sand ≤ 600 μm	1013	40.52
Superplasticizer	17	0.68
Steel fibers	140	5.60
Water	185	7.40

The main task of this work is to examine the effect of the addition of steel and polypropylene fibers on selected properties of fine-grained concrete in order to later use observed regularities for RPC design. The recipe was limited only to the necessary ingredients (cement, aggregate, fibers, water) to avoid the influence of other components on the properties of the mixture and finished concrete.

2. MIXTURE RECIPES AND SAMPLES

For the purpose of laboratory tests, 3 cubes 15x15x15 cm and 3 cuboid bars 10x10x50 cm were prepared from 7 concrete mixtures (Table 2) with different content of steel and polypropylene fibers. There were 42 samples in total. Cement CEM III/A 32,5N-LH/HSR/NA from the EKOCEM cement plant in Dabrowa Gornicza, polypropylene macro-fibers Sika Enduro HPP 50, steel macro-fibers NOVOCON XR1050 and fine-grained natural aggregate with the grain-size distribution curve as in Fig. 1 were used to prepare concrete mixtures. For the assumed formulations, the tightness equation was fulfilled.

$$\frac{C}{\rho_C}+\frac{F}{\rho_F}+\frac{W}{\rho_W}+\frac{S}{\rho_S}=1 \tag{2.1}$$

where:

C, F, W, S – quantity [kg/m^3]: cement, fibers, water, sand;
ρ_c, ρ_F, ρ_w, ρ_S – density [kg/m^3]: cement, fibers, water, sand.

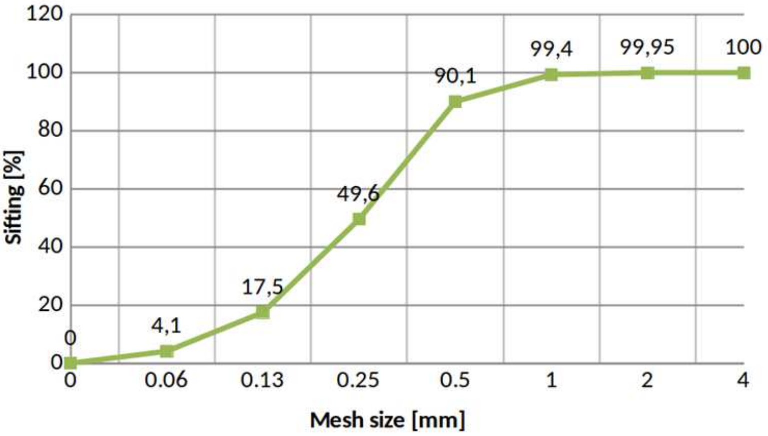

Fig. 1. The grain-size distribution curve of the applied fine-grained aggregate

Table 2. Designed concrete mix recipes

	Percentage content fibers						
	0%	5%	10%	20%	1,5%	2,5%	3,48%
Determination of the mixture	M I	M II	M III	M IV	M V	M VI	M VII
Cement [kg/m^3]	650	650	650	650	650	650	650
Steel fibers NOVOCON XR1050 [kg/m^3]	-	115.5	231	462	-	-	-

Polypropylene fibers Enduro HPP 50 [kg/m^3]	-	-	-	-	34.65	57.75	80.39
Sand [kg/m^3]	1400	1375	1325	1250	1300	1250	1175
Water	260	260	260	260	260	260	260
W/C	0.40	0,40	0.40	0.40	0.40	0.40	0.40
Volume [kg/m^3]	2310	2401	2466	2622	2245	2218	2165
The tightness equation	1.0	1.0	1.0	1.0	1.0	1.0	1.0

After the samples were made, they were seasoned for 28 days in the thermal-humid conditions as in Figure 2. For the first 48 hours, the samples were stored under constant thermal and humid conditions in accordance with PN-EN 12390-2: 2011 [6].

3. RESULTS OF THE LABORATORY TESTS

3.1 Consistency testing

Testing the consistency of designed concrete mixtures was carried out with the use of a drop cone method in accordance with PN-EN 12350-2: 2011 [5]. The obtained results are presented in table 3.

Table 3. The results of testing the consistency of designed mixtures

Determination of the mixture	Fibers	Drop cone [mm]	Consistency class	
M I	0	90	Semi liquid	K4
M II	5% steel	50	Plastic	K3
M III	10% steel	40	Plastic	K3
M IV	20% steel	20	Plastic	K3
M V	1.5% polypropylene	20	Dense plastic	K2

Volumetric density of polypropylene fibers 940 kg/m^3 is several times lower in comparison to density of steel fibers. Mixture M VI contained the maximum 2.5% addition of polypropylene fibers which allowed to maintain the concrete workability at the acceptable level. For this mixture, no slump of the concrete cone was observed. It was not possible to prepare mixture M VII in a counter-rotating concrete mixer; therefore, samples from this series were prepared in such a way that fibers were placed in molds and then the concrete mixture was poured onto them. All samples after having been placed in molds were appropriately thickened.

3.2 Contraction test

The contraction test was carried out on 10x10x50 cm rectangular bars using the Amsler apparatus. The first measurement of shrinkage was made after 48 hours of the samples being made. Samples from the moment of execution from the first measurement were stored in constant thermal and humid conditions in accordance with PN-EN 12390-2: 2011 [6]. After 48 hours, samples were stored at an average temperature of 21°C, and average air humidity: 36.8 %. The exact distribution of temperature and air humidity during the 28-day seasoning of samples is shown in the graph in Figure 2. Figure 3 shows the course of average time shrinkage for beams made of individual mixtures (table 2). Three bars made of each mix were used for the study. The results were averaged.

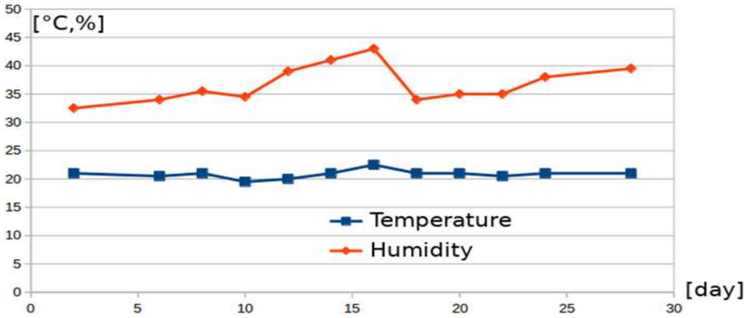

Fig. 1. Distribution of temperature and air humidity during the contraction test

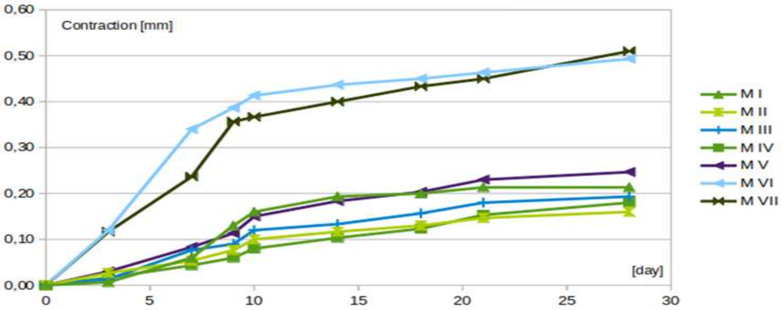

Fig. 2. Medium shrinkage of beams made of individual mixtures

While analyzing the obtained results it can be observed that the addition of steel fibers reduces concrete shrinkage, while the use of polypropylene fibers, particularly in a greater amount, significantly increases it.

3.3 Compressive strength test

The compressive strength test comprised cubic samples with a side of 15 cm. Each of the samples ripened at least 28. The study was carried out in accordance with PN-EN 12390-3:2011 [7]. Strength classes of the tested concrete were determined on the basis of PN-EN 206-1:2003 [10].

Table 4. The results of the compressive strength test

Sample mark	P_c [kN]	$f_{c,28}$ [MPa]	P_{cm} [kN]	$f_{cm,28}$ [MPa]	Class of concrete
M I 1	918.2	40.01	1009.90	48.14	C40/50
M I 2	1140.1	56.32			
M I 3	971.4	48.09			
M II 1	1150.3	51.15	1060.33	50.51	C45/55
M II 2	1005.5	49.69			
M II 3	1025.2	50.68			
M III 1	931.5	40.96	1119.15	53.60	C40/50
M III 2	1213.5	59.94			
M III 3	1212.4	59.89			
M IV 1	1044.1	50.81	1131.40	55.65	C50/60
M IV 2	1193.7	58.95			
M IV 3	1156.4	57.20			
M V 1	649.7	27.54	832.92	39.63	C30/37
M V 2	952.9	47.07			
M V 3	892.2	44.27			
M VI 1	899.3	39.97	944.00	45.14	C40/50
M VI 2	928.1	45.84			
M VI 3	1004.6	49.61			
M VII 1	479.1	23.67	619.00	30.57	C25/3
M VII 2	671.3	33.15			
M VII 3	706.6	34.89			

where P_c - destructive force of the sample, f_c,28 - compressive strength of concrete after 28 days calculated from the formula:

$$f_{c,28} = \frac{P_c}{A} \tag{3.1}$$

A - cross-sectional area of the sample 225cm^2, P_{cm} – average destructive force of the sample, f_{cm},28 – average compressive strength of concrete after 28 days.

Within the tested range, results confirm the positive influence of the addition of steel fibers on compressive strength of concrete. Polypropylene fibers lowered compressive strength of tested samples.

3.4 Bending strength test

The bending strength test was carried out on rectangular bars 10x10x50 cm, according to PN-EN 12390-5:2011 [8]. Samples were tested during the four-point bending test, figure 4.

Table 5. The results of the bending strength test

Sample mark	F [kN]	Average damage force [kN]	f_{cf} [MPa]
M I 1	10.03	8.82	2.65
M I 2	8.56		
M I 3	7.87		
M II 1	12.37	11.26	3.38
M II 2	11.31		
M II 3	10.11		
M III 1	16.25	20.41	6.12
M III 2	26.29		
M III 3	18.70		
M IV 1	29.53	25.37	7.61
M IV 2	20.87		
M IV 3	25.71		
M V 1	8.15	9.04	2.71
M V 2	8.18		
M V 3	10.80		
M VI 1	12.35	14.19	4.26
M VI 2	13.85		
M VI 3	16.38		
M VII 1	6.61	12.75	3.83
M VII 2	16.04		
M VII 3	15.60		

where:

$$f_{cf} = \frac{F \cdot l}{d^3} \tag{3.2}$$

f_{cf} – theoretical bending strength;
F – load destroying the sample;
l – distance between supports;
d – length of the cross-section side of a sample.

The addition of steel and polypropylene fibers in the tested range increased bending strength.

Fig. 4. Bending strength test

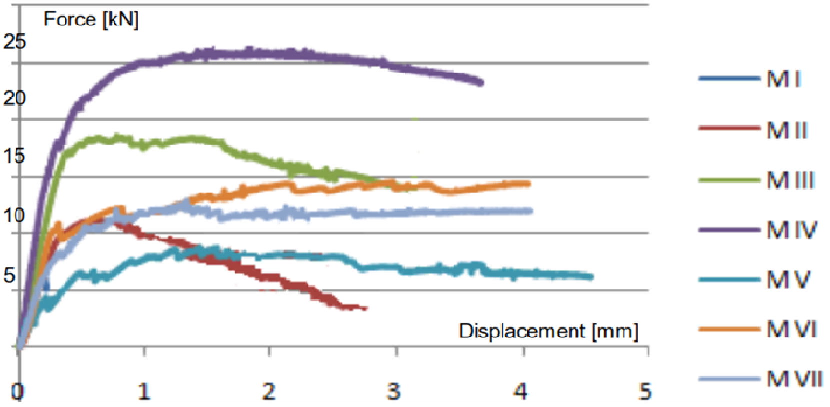

Fig. 5. Averaged load-displacement curves of tested samples

3.5 Water-tightness test

Cubic samples with a size of 15x15x15 cm. were tested for water-tightness. Each of the samples ripened at least 28 days. Before starting the test, all samples were dried to a constant mass in accordance with PN EN 12390-8:2011 [9]. The test was carried out on a standard apparatus for testing water-tightness of concrete (fig. 6). The water pressure exerted on the samples was lifted every 24 hours from 0.2 MPa to 1.2 MPa. The all samples remained sealed until the maximum pressure was reached. Table 3.4 presents the results of the water-tightness test of the samples made. The soaking level was read at the sample breakthroughs (fig. 7).

Fig. 6. Samples during the test of water-tightness

Table 6. Results of water-tightness test

Sample mark	Soaking level		Water-tightness class
	[mm]	Average value [mm]	
M I 1	141	142.0	W4
M I 2	146		
M I 3	139		
M II 1	148	133.3	W4
M II 2	119		
M II 3	133		
M III 1	128	122.3	W4
M III 2	124		
M III 3	115		
M IV 1	141	135.7	W4
M IV 2	137		
M IV 3	129		
M V 1	98	109.7	W4
M V 2	134		

M V 3	97		
M VI 1	105	104.7	W4
M VI 2	112		
M VI 3	97		
M VII 1	143	120.7	W4
M VII 2	115		
M VII 3	104		

Fig. 7. Reading the soaking level at the turn of the sample

Results of the test of water-tightness did not demonstrate any significant influence of the addition of fibers on this parameter.

4. CONCLUSIONS

On the basis of the conducted tests, the following conclusions can be drawn:

- within the tested range, the addition of steel fibers to fine-grained concrete does not deteriorate to a significant extent its workability, while polypropylene fibers significantly deteriorate the mixture's workability;
- within the tested range, the addition of steel fibers reduces concrete shrinkage, while the use of polypropylene fibers particularly in a greater amount significantly increases it;
- within the tested range, steel fibers increase and propylene fibers lower compressive strength of concrete;
- the addition of steel and polypropylene fibers in the tested range increases bending strength;
- within the tested range, the addition of both types of fibers does not significantly influence concrete water-tightness.

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WPŁYW DODATKU WŁÓKIEN STALOWYCH I POLIPROPYLENOWYCH NA WYBRANE WŁAŚCIWOŚCI BETONU DROBNOZIARNISTEGO

Streszczenie

W artykule zaprezentowano wyniki badań laboratoryjnych wybranych właściwości mechanicznych i fizycznych fibrobetonów drobnoziarnistych. Badania przeprowadzono na próbkach o różnym stopniu zbrojenia wykonanych na bazie włókien stalowych oraz polipropylenowych. Dla zaprojektowanych mieszanek betonowych oraz wykonanych próbek wyznaczono klasę konststencji, skurcz, wytrzymałość na ściskanie i zginanie oraz wodoszczelność.

Słowa kluczowe: włókna, beton drobnoziarnisty, badania laboratoryjne

Editor received the manuscript 08.10.2018