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CONTRIBUTION TO THE KNOWLEDGE ON INFLUENCE OF POLYPROPYLENE FIBRES ON SELECTED PROPERTIES OF SELF-COMPACTING CONCRETE

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Abstract. The self-compacting concrete proved to be the most revolutionary achievement of the engineering in the last 25 years. Its numerous advantages encourage an expanding research of this composite. One of the aspects of the research is its properties modification by an addition of fibres as a dispersed reinforcement. In the technology of the self-compacting concrete this problem is still not sufficiently solved. The technology of the self-compacting concrete is a difficult subject due to a large "sensitivity" of the composite on any qualitative and quantitative variation of mix components. An increase of a fibre content in a volume of the self-compacting concrete enhances properties of a hardened composite and on the other hand deteriorates its properties during the forming stage. The paper presents results of experiments on an influence of polypropylene fibres on selected properties of the self-compacting concrete. It is concluded, that a small addition of the fibres does not evoke any change in rheological properties of the concrete mix. Only a small disturbation of self-deaeration was observed leading to a small increase of concrete porosity and water absorption. The fibres decreased the concrete shrinkage, increased water tightness and did not cause any decrease of compressive strength.

Key words: self-compacting concrete, polypropylene fibre, shrinkage, water absorption, water tightness, compressive strength

INTRODUCTION

The most revolutionary achievement in the concrete technology in the last twenty five years proved to be the self-compacting concrete [Szwabowski and Śliwiński 2003, Kaszyńska 2004, Szwabowski and Gołaszewski 2010]. It is a cement composite charac-

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terised by the high strength, tightness and durability [Stefańczyk and Rudnicki 2002]. These properties are obtained by a proper qualitative and quantitative selection of concrete components including: high efficient superplasticisers, which increase cohesion of the concrete mix for a longer time, despite its free fluidity; mineral additives (fly ash, finely ground blast-furnace slag, micro-silica as well as lime and dolomite flours) serving as micro-fillers [Szwabowski and Śliwiński 2003, Kaszyńska 2004, Pereira de Oliveira et al. 2004, Brouwers and Radix 2005, Szwabowski and Gołaszewski 2010, Neville 2012] as well as viscosity modifying admixtures (VMA), which are more and more frequently mentioned in the literature [Rixom and Mailvaganam 1999, Woyciechowski 2006, Szwabowski and Gołaszewski 2010, Grabiec 2012].

Technology of the self-compacting concrete eliminates a mechanical compacting during the forming process. Filling of formworks with a mix is more efficient because there is no need to place it in layers. The construction time is shortened, investment costs are reduced and the noise emission is decreased [Stefańczyk and Rudnicki 2002, Szwabowski and Śliwiński 2003, Kaszyńska 2004, Szwabowski and Gołaszewski 2010].

Numerous advantages of the self-compacting concrete encourage a continuous research of this composite. One of ways to modify its properties is an addition of various types of fibres as a dispersed reinforcement. In the case of the self-compacting concrete this is a new issue [Corinaldesi and Moriconi 2004, Richardson 2006, Ponikiewski and Szwabowski 2006]. It is also difficult one, due to a high susceptibility of this composite on any qualitative or quantitative changes of its composition. An important problem is a recognition of a real nature of workability of the self-compacting concrete with fibres and an assessment of their influence on properties of the hardened concrete.

The key issue of an application of a dispersed reinforcement was to improve properties of brittle materials combining them with an elastic material. After some time concrete with steel and polypropylene fibres became commonly used. The creation of composites with fibres is related to a protection of building structures against seismic loading and it was pioneered by Japanese and Americans.

Natural phenomena of shrinkage and temperature change due to hydration heat production in concrete lead during setting and initial hardening periods to breaking and cracking. Polypropylene fibres are mainly used [Petri 1996, Petri and Spisak 1998, Woyciechowski 2000] to prevent formation of shrinkage cracks or, more precisely, to reduce microcracking in a new concrete. Studies on early age shrinkage of polypropylene fiber reinforced self-compacting concrete show that by blocking aggregate settling and moisture floating, fibres can reduce number of capillary, slow down the evaporation and reduce the mass loss of fresh concrete [Liu and Ding 2008].

Natural shrinkage cracks in concrete cannot be completely eliminated but thanks to the application of polypropylene fibres the cracks are not visible and have little influence on water tightness and strength of concrete.

An action of fibres ceases after a time, when the increasing value of concrete Young's modulus exceeds the one for polypropylene. In the case of a simultaneous use of steel and polypropylene fibres (hybrid reinforcement) the former ones become active. The polypropylene fibres increase concrete resistance to fire temperatures. At the temperature of 160°C the polypropylene fibres melt leaving voids. In this way small channels are formed allowing for vapour escape, what prevents pressure increase and explosive spalling.

However, according to the data of Jansson and Boström [2010] regarding fire tests on self-compacting concretes with polypropylene fibres, the pressure in the capillary system is not the driving force for spalling during fire exposure. Polypropylene fibres are assumed to reduce the moisture content in the critical zone close to the heated surface which affects the mechanical properties advantegously, and amplify moisture movement leading to larger drying creep and shrinkage which locally relaxes the thermal stresses [Jansson and Boström 2013]. It confirms conclusions of Noumove et al. [2006] that adding polypropylene fibres improves the thermal stability of self-compacting concrete. Liu et al. [2008] conclude that the connectivity of pores as well as the creation of microcracks are the major factors which determine the gas permeability after exposure to high temperature. According to Al Qadi et al. [2011] the susceptibility of self-compacting concrete to spalling increases with the degree of ingredient materials used in the concrete, including polypropylene fibres.

The results of tests carried out by Tao et al. [2009] show that a certain amount of polypropylene fibres could minimise the risk of spalling for self-compacting concrete at high temperatures. The effect of stress level on spalling is significant. However, probability of spalling is higher for specimens in compression than for unloaded specimens.

Polypropylene fibres do not influence significantly mechanical properties of concrete. Concrete reinforced with these fibres exhibits smaller water absorption and water permeability, increased frost and abrasion resistance as well as higher durability under dynamic loading [Jasiczak and Mikołajczyk 1997, Karwacki 2001]. According to the newest data of He and Yan [2013] strength properties of the self-compacting concrete, which are reinforced with polypropylene monofilament fibres of different volume fractions are improved significantly. Some other authors [Gencel et al. 2012, Aslani and Nejadi 2013] come to the same conclusion regarding enhancing the strength (compressive, splitting tensile and flexural) of self-compacting concrete after addition of polypropylene fibres.

Water permeability and chloride ion penetrability of self-compacting concrete are decreased due to the polypropylene fibres [He and Yan 2013]. In general self-compacting concrete modified with polypropylene fibres behaves well or better than normal concrete to internal frost except for the submerged cast concrete. However, in some cases fibres are able to prohibit the movement of water in the air void system so that a sudden internal collapse may occur [Persson 2006].

It is in contradiction to some authors' opinion that addition of polypropylene fibres deteriorates workability of concrete mix but to a smaller extent than that of steel fibres [Szwabowski and Gołaszewski 2010]. Gencel et al. [2012] point out to the fact that polypropylene fibres exhibit no problems with mixing or workability when the fibre distribution is uniform.

MATERIALS, ASSUMPTIONS, SCOPE AND TESTING PROCEDURE

The Portland cement CEM I 32.5 R was selected to prepare self-compacting mixes. It fulfilled the requirements of the standard EN 197-1. A fly ash fulfilling the requirements of the standard EN 450-1 was chosen as the micro-filler. Some characteristics of cement and fly ash used in the study are given in Tables 1 and 2, respectively. The superplasticiser of the third generation with a polycarboxylate-basis served as a fluidifying admixture. To modify the self-compacting concrete polypropylene fibres were used. They were straight with ribbed surface and had 48 mm length.

Table 1. Composition, physical and mechanical properties of cement
Tabela 1. Skład, właściwości fizyczne i mechaniczne cementu

Characteristic – Cecha	Result – Wynik
Chemical components [%] Skład chemiczny [%]	
SO_3	2.70
Cl^-	0.019
Na_2Oeq	0.83
Insoluble residue [%] Części nierozpuszczalne [%]	0.52
Ignition loss [%] Straty prażenia [%]	2.30
Potential compounds [%] Skład mineralogiczny [%]	
C_3S	57.0
C_3A	10.0
Blaine's specific surface [$m^2 \times kg^{-1}$] Powierzchnia właściwa wg Blaine'a [$m^2 \times kg^{-1}$]	328
Initial setting time [min] Początek czasu wiązania [min]	180
Compressive strength [MPa] Wytrzymałość na ściskanie [MPa]	
2 days 2 dni	11.6
28 days 28 dni	36.8

Table 2. Physical properties and chemical composition of fly ash
Tabela 2. Właściwości fizyczne i chemiczne popiołu lotnego

Characteristic – Cecha	Result – Wynik
Ignition loss [%] – Straty prażenia [%]	3.05
Fineness [%] – Powierzchnia właściwa [%]	23.7
Density [$g \times cm^{-3}$] – Gęstość [$g \times cm^{-3}$]	2.14
28-day pucolane activity factor [%] Wskaźnik aktywności po 28 dniach [%]	79.0
Free lime content [%] Zawartość wolnego wapna [%]	0.12
SO_3 content [%] – Zawartość SO_3 [%]	0.43
Cl^- content [%] – Zawartość chlorków [%]	0.01

Self-compacting criteria for concrete mixes were determined from the maximal flow of the mix from the reversed Abrams cone, the time of the 500 mm diameter flow range from the Abrams cone and the air content in the mix [Szwabowski and Śliwinski 2003, Kaszyńska 2004, The European Guidelines… 2005]. It is worth pointing out that according to The European Guidelines… [2005], measurement of the time for the 500 mm slump-flow may be omitted if not requested. The European Guidelines… [2005] does not specify any requirements concerning the air content in the concrete mix, either. Hence, the present authors adopted the ranges individually and took into consideration the time of the 500 mm diameter flow as a particularly important criterion for self-compacting concrete mixes modified with fibres.

Taking into account some differences in recommendations concerning the self-compacting criteria for mixes without fibres [Szwabowski and Śliwiński 2003, Kaszyńska 2004, The European Guidelines… 2005], the self-compacting limit for mixes modified with steel fibres proposed by Ponikiewski and Szwabowski [Ponikiewski and Szwabowski 2006] (time of the 500 mm flow till 9 seconds and the maximal flow diameter about 600 mm) and the lack of unique indications in this aspect for concrete mixes with polypropylene fibres the following ranges were assumed in the experiments:

– the diameter of the slump-flow from the inversed Abrams cone after a stabilisation in the range of 650–800 mm,
– time for the 500 mm slump-flow of the mix from the inversed Abrams cone not exceeding 8 seconds,
– air content in the mix after the self-compacting not exceeding 6%.

The basic composition of concrete was: cement = 365 kg×m^{-3}, gravel 8–16 mm = 655 kg×m^{-3}, gravel 2–8 mm = 546 kg×m^{-3}, sand = 591 kg×m^{-3}, fly ash = 91 kg×m^{-3}, water/ /cement ratio w/c = 0.33, superplasticiser 2.5% of the cement mass. The amounts of fibres: 2 and 4 kg×m^{-3} were assumed basing of the initial experiments where 2 to 9 kg×m^{-3} of fibres were used checking the fulfillment of the assumed self-compacting criteria (Table 3).

Table 3. Properties of self-compacting concrete mixes (preliminary experiments)
Tabela 3. Właściwości samozagęszczalnych mieszanek betonowych (badania wstępne)

Designation of concrete mix Oznaczenie mieszanki betonowej	Amount of fibres [kg×m^{-3}] Ilość włókien [kg×m^{-3}]	Time of flow to 500 mm diameter [s] Czas rozpływu do średnicy 500 mm [s]	Maximal flow diameter [mm] Maksymalna średnica rozpływu [mm]
w0	0	6.0	720/730
w2	2	6.5	710/720
w3	3	7.7	690/700
w4	4	7,0	690/700
w5	5	7.2	730/740
w6	6	7.6	730/750
w7	7	8.9	710/720
w8	8	9.3	700/700
w9	9	9.5	690/700

Procedures concerning testing of the air content in concrete mixes and the properties of hardened concrete, like: bulk density, water absorption and water tightness (after 28 days of maturing) and compressive strength (after: 1, 2, 7 and 28 days) corresponded to the standards: EN 12350-7, EN 12390-8 and EN 12390-3.

The air content in concrete mixes was determined using the autoclave type 8 L B 2020 of Swiss make.

The bulk density, the water absorption and the compressive strength of concrete was measured using cubic specimens of 150 × 150 × 150 mm dimensions. Three specimens per series per each parameter were used in the testing.

The water tightness was tested using six cubic specimens of 150 × 150 × 150 mm dimensions for each series. The specimens were placed in a pressure apparatus and subjected to the action of water under the constant pressure of 0.5 MPa during 72 hours. To avoid an uncontrolled water leaking the sides of the specimens subjected to the pressure were sealed using an epoxy resin layer. The range of this layer was assumed in a way enabling the testing of the clean unsealed surface of 75 mm diameter. After the testing time the specimens were taken out from the apparatus, the upper surfaces, which contacted with water were wiped and immediately afterwards the specimens were broken in the direction parallel of the water action in order to determine the penetration depth.

The compressive strength was determined using the strength machine 107/3000 A DIG. 2000-P.C of Swiss make.

Testing of shrinkage were carried out using concrete beams of 100 × 100 × 500 mm dimensions with dial gauges installed, which allowed measurements with 0.01 mm accuracy. The measurements commenced 24 hours after casting.

The results of the tests concerning the water absorption, water tightness and compressive strength of concrete were compared using the statistical analysis of variance. The results of water absorption and water tightness tests were, in turn, analysed using the one-factor analysis. As the compressive strength of concrete was analysed after 1, 2, 7 and 28 days, the results of the tests were compared using the repeated measures analysis of variance. In order to prove a statistically significant difference in mean values between particular series, the Scheffé's test was performed for each test. The results of the tests were presented as homogeneous groups, i.e. groups in which the differences between mean values are not statistically significant. In the all tests the alpha significance level was at 5% (α = 0.05). Calculations were performed using *Statistica* (Software programme, licence no. JGNP 105B037825 AR-A).

RESULTS AND DISCUSSION

The air content and initial consistence with their changes in time for the concrete mixes are presented in Table 4. Testing results of bulk density, water absorption and water tightness measurements for concrete with and without fibres are given in Table 5, while those for shrinkage – in Figure 1. Results of compressive strength testing for concrete with and without fibres are presented in Figure 2.

The results of the air content measurements for the mixes without and with fibres presented in Table 4 show, that in the mix without fibres it was about 0.5% smaller than in the ones with fibres. Hence, a conclusion can be formulated, that the fibres in the amount of 2 and 4 kg×m^{-3} deteriorate in a small extent the ability of the mix to self-deaerate.

Table 4. The air content, initial consistence and their changes in time for self-compacting concrete mixes
Tabela 4. Zawartość powietrza w samozagęszczalnych mieszankach betonowych, ich konsystencja wyjściowa i zmiany w czasie

Designation of concrete mix Oznaczenie mieszanki betonowej	Amount of fibres [kg×m^{-3}] Ilość włókien [kg×m^{-3}]	Air content [%] Zawartość powietrza [%]	Elapsed time [min] before testing: Czas [min] przed rozpoczęciem testu: 0	15	30	45	60
			Time of the flow to 500 mm diameter [s] and the maximal flow diameter [mm] Czas rozpływu do średnicy 500 mm [s] i maksymalna średnica rozpływu [mm]				
w0	0	1.9	6.5	8	9.3	10.5	–
			700/730	690/710	680/700	670/680	–
w2	2	2.4	7.4	8.1	8.4	12.9	17.9
			680/700	680/690	680/700	620/620	610/620
w4	4	2.5	7.2	8.1	9.1	11.6	18.3
			690/700	690/700	680/690	650/650	620/630

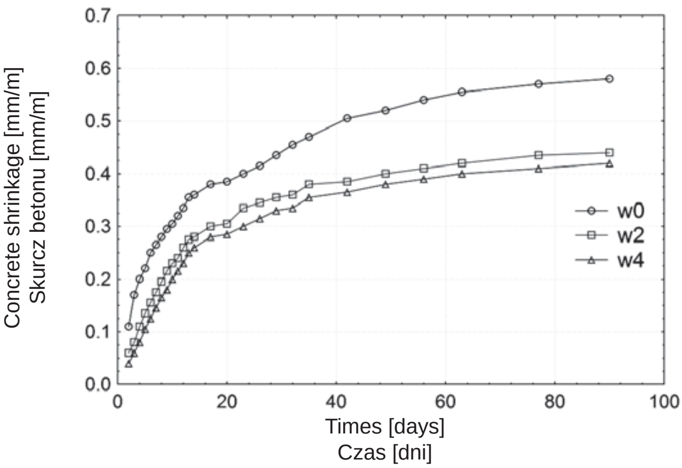

Fig. 1. Variation of self-compacting concrete shrinkage vs. time (w0 – concrete without fibres; w2 – concrete with 2 kg×m^{-3} of fibres; w4 – concrete with 4 kg×m^{-3} of fibres)
Rys. 1. Zmiany skurczu betonu samozagęszczalnego w czasie (w0 – beton bez włókien; w4 – beton z 2 kg×m^{-3} włókien; w4 – beton z 4 kg×m^{-3} włókien)

The results of testing of concrete mixes show, that the addition of 2 or 4 kg×m^{-3} of polypropylene fibres influenced in a small degree the ability of the mix to flow (Tables 3 and 4), while fibres used in amount exceeding 6 kg×m^{-3} deteriorate this property (Table 3). This is visible in the results of the 500 mm diameter slump-flow time as well as the values of the maximal slump-flow carried out as the initial testing. These observation lead to a conclusion, that there exists a certain quantity range for the fibres, for which their negative influence on the rheological properties of the concrete mix is negligible.

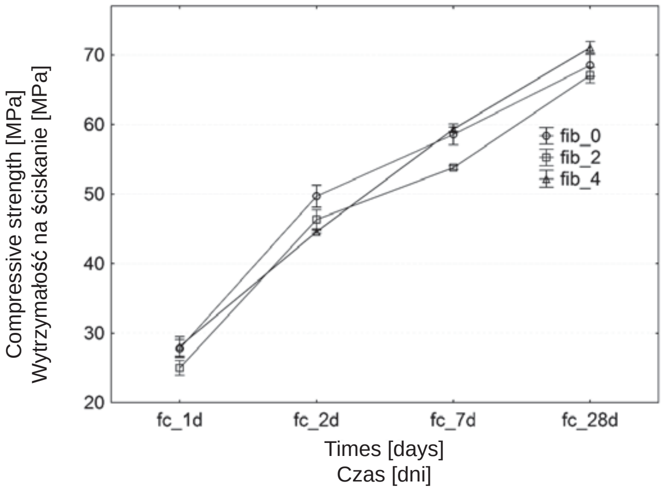

Fig. 2. Variation of self-compacting concrete compressive strength vs. time (w0 – concrete without fibres; w2 – concrete with 2 kg×m^{-3} of fibres; w4 – concrete with 4 kg×m^{-3} of fibres)

Rys. 2. Zmiany wytrzymałości na ściskanie betonu samozagęszczalnego w czasie (w0 – beton bez włókien; w2 – beton z 2 kg×m^{-3} włókien; w4 – beton z 4 kg×m^{-3} włókien)

The results of the bulk density measurements (Table 5) indicate, that the addition of the polypropylene fibres caused a slight decrease of this parameter. It is supposed, that the reason is due to a relatively small density of the polypropylene and a certain aeration of the mix due to the presence of the fibres. However, according to Richardson [2006] such an explanation of this phenomenon is dubious. The author suggests that high water retention and as result low bleeding could provide greater hydration of the cement, thus creating a larger volume of cement paste with subsequent evaporation pockets, leading to lower density.

Concrete water absorption after 28 days of maturing was similar (Table 5). In the case w0 (concrete without fibres) it was about 3.5% and for the cases w2 (concrete with 2 kg×m^{-3} of fibres) and w4 (concrete with 4 kg×m^{-3} of fibres) – 3.9%. It is emphasised in the literature on the polypropylene fibres, that they decrease water absorption but this concerns composites compacted in a traditional way. Fibres added to the tested self-compacting mixes slightly reduced the ability of self-deaeration under the self-weight, what increased porosity and, consequently, water absorption.

The addition of the fibres improved water tightness of concrete. The depth of water penetration for the concrete samples for the series w0 (concrete without fibres) was 25.8 mm and decreased to 24.9 mm and 22 mm in concrete with 2 and 4 kg×m^{-3} of fibres, respectively (Table 5).

The testing showed, that the polypropylene fibres caused a decrease of concrete shrinkage (Fig. 1). The mean value of shrinkage in the case w0 (concrete without fibres) was 0.58 mm/m and for the cases w2 (concrete with 2 kg×m^{-3} of fibres) and w4 (concrete with 4 kg×m^{-3} of fibres) – from 0.42 to 0.44 mm/m.

Table 5. Bulk density, water absorption and water tightness of self-compacting concretes
Tabela 5. Gęstość objętościowa, nasiąkliwość i wodoprzepuszczalność betonów samozagęszczalnych

Designation of concrete series Oznaczenie serii betonu	Amount of fibres [kg×m^{-3}] Ilość włókien [kg×m^{-3}]	Bulk density [kg×m^{-3}] Gęstość objętościowa [kg×m^{-3}]	Water absorption [%] Nasiąkliwość [%]	Depth of water penetration [mm] Głębokość przenikania wody [mm]
w0	0	2.386	3.47	25.8
w2	2	2.380	3.86	24.9
w4	4	2.370	3.88	22.0

The statistical analysis showed a statistically significant difference in the results of water absorption tests between the control batch and batches with polypropylene fibres (Table 6). The analysis of the results of water tightness tests showed that there is no difference between the series (Table 7). However, when additionally Tukey's test (considered to be less conservative) was performed instead of the Scheffé's test, it was found that the batch with the largest fibre content (4 kg×m^{-3}) differed from the remaining batches, showing less deep water penetration (Table 8). In general, the results of the analyses for both the above-mentioned tests suggest that propylene fibres, despite a minimal increase in the water absorption of concrete (from about 3.5% to almost 3.9%), do not result in a significant loss of the performance characteristics of concrete, which are significant from the point of view of its durability. This conclusion is not in conflict with the result of the Scheffé's test, i.e. a statistically significant difference between the w0 series and the w2 and w4 series, taking into account the fact that fibres reduce the shrinkage of self-compacting concrete (Fig. 1), which may result in scratches and reduce the quality of concrete by causing cracks to develop and spread, creating an additional transport route for aggressive substances interacting with concrete.

Table 6. Results of Scheffé's test for water absorption
Tabela 6. Wyniki testu Scheffé'go dla nasiąkliwości betonu

Subclass No. Numer podklasy	Scheffe's test; W_abs; alpha = 0.05 – Test Scheffé'go; W_abs; alfa = 0.05 Error: MS between groups = 0.03233, df = 12.000 Błąd: średni kwadratowy międzygrupowy = 0,03233; df = 12,000			
	fib_cont [%] zawartość włókien [%]	W_abs Avg [%] nasiąkliwość średnia [%]	1	2
1	0	3.470000		***
2	2	3.860000	***	
3	4	3.880000	***	

MS – Mean Squares; df – difference.
MS – średni kwadrat; df – różnica.

Table 7. Results of Scheffé's test for water penetration depth
Tabela 7. Wyniki testu Scheffé'go dla wodoprzepuszczalności

Subclass No. Numer podklasy	Scheffe's test; W_pd; alpha = 0.05 – Test Scheffé'go; W_pd; alfa = 0.05 Error: MS between groups = 4.7500, df = 12.000 Błąd: średni kwadratowy międzygrupowy = 4,7500; df = 12,000		
	fib_cont [%] zawartość włókien [%]	W_pd Avg [mm] wodoprzepuszczalność średnia [mm]	1
3	4	22.00000	***
2	2	24.90000	***
1	0	25.80000	***

MS – Mean Squares; df – difference.
MS – średni kwadrat; df – różnica.

Table 8. Results of Tukey's test for water penetration depth
Tabela 8. Wyniki testu Tukeya dla wodoprzepuszczalności

Subclass No. Numer podklasy	HSD Tukey's test; W_pd; alpha = 0.05 – Test HSD Tukey'a; W_pd; alfa = 0.05 Error: MS between groups = 4.7500, df = 12.000 Błąd: średni kwadratowy międzygrupowy = 4,7500; df = 12,000			
	fib_cont [%] zawartość włókien [%]	W_pd Avg [mm] wodoprzepuszczalność średnia [mm]	1	2
3	4	22.00000	***	
2	2	24.90000	***	***
1	0	25.80000		***

MS – Mean Squares; df – difference.
MS – średni kwadrat; df – różnica.

Compressive strength of the self-compacting concrete in the variants with and without fibres remained at the similar level (Fig. 2), what allows to conclude, that the polypropylene fibres did not influence significantly this property. There exist various data concerning the polypropylene fibres influence on compressive strength of an ordinary concrete. Sometimes an increase is reported and on another occasions – a decrease [Richardson 2006]. The contradictory data result from differences in concrete composition, type of fibres and conditions of concrete preparation. Data for the self-compacting concrete are lacking.

The results of the performed statistical analysis show that the mean values of the compressive strength of concrete tend not to differ between the w0, w2 and w4 series on subsequent days on which the tests were performed. In almost all cases, at least two out of three means form one group, while some mean values belong to two groups simultaneously. The only case in which the test showed a group with only one value, significantly different from the remaining ones, was the result for the w2 batch after 7 days of the hardening of concrete (Table 9). It is difficult to pinpoint the reason for this exception. However, the statistical analysis generally suggests that a 2–4 kg×m^{-3} content of propylene fibres in the entire mass of concrete does not reduce the compressive strength of self-compacting concrete.

Table 9. Results of Scheffé's test for compressive strength in the repeated measures design
Tabela 9. Wyniki testu Scheffé'go dla wytrzymałości na ściskanie w powtarzanych pomiarach

Scheffe's test; fc_d; alpha = 0.05 – Test Scheffé'go; W_pd; alfa = 0.05 Error: MS between groups, repeated measures, linked = 1.3376, df = 12.000 Błąd: średni kwadratowy międzygrupowy, powtarzane pomiary, połączony efekt									
fib_cont [%] Zawartość włókien [%]	time [days] czas [dni]	fc_d Avg [MPa] wytrzymałość na ściskanie średnia [MPa]	1	2	3	4	5	6	7
2	1	25.0	***						
0	1	27.8	***						
4	1	28.1	***						
4	2	44.6		***					
2	2	46.3		***	***				
0	2	49.7			***				
2	7	53.8							***
0	7	58.6				***			
4	7	59.3				***			
2	28	67.1					***		
0	28	68.5					***	***	
4	28	71.1						***	

MS – Mean Squares; df – difference.
MS – średni kwadrat; df – różnica.

Summing up, the study showed that the shrinkage of concrete may be efficiently reduced by a 2–4 kg×m^{-3} addition of polypropylene fibres. Moreover, the addition of polypropylene fibres does not affect the durability of concrete negatively and only results in a minimal increase in water absorption and even in a minimal decrease in water tightness in the case of the w4 series.

CONCLUSIONS

The following conclusions can be drawn from the results of our investigations:

1. Too high content of polypropylene fibres (more than 6 kg×m^{-3}) is not justified technologically due to the failure to fulfill the criteria of concrete mix self-compactibility.

2. Fibres applied in a smaller amount (from 2 to 4 kg×m^{-3}) do not deteriorate significantly the self-compacting properties of a concrete mix and only slightly disturbed its ability to deaerate. Concrete with such an amount of fibres is characterised by a small

increase of water absorption and a simultaneous slight improvement of water tightness but only difference in water absorption is proved statistically. However, additionally used Tukey's test regarding water tightness results shows that fibres in amount of 4 kg×m^{-3} lead to significant difference in comparison to concrete without polypropylene fibres.

3. The 28-day strength of the tested concrete types does not differ significantly. The results are enhanced by the results of Scheffé's test.

4. Definitely, the most advantageous influence of the polypropylene fibres addition in the self-compacting concrete is in a reduction of shrinkage strain during the first 90 days of concrete hardening.

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O WPŁYWIE WŁÓKIEN POLIPROPYLENOWYCH NA WYBRANE WŁAŚCIWOŚCI BETONU SAMOZAGĘSZCZALNEGO

Streszczenie. Beton samozagęszczalny jest jednym z najbardziej spektakularnych osiągnięć w budownictwie w ciągu ostatniego ćwierćwiecza. Korzyści wynikające z jego zastosowania w praktyce budowlanej zachęcają do ciągłego poszerzania badań nad tym kompozytem cementowym. Jednym z kierunków badawczych jest modyfikacja właściwości poprzez dodawanie włókien jako zbrojenia rozproszonego. W technologii betonu samozagęszczalnego zagadnienie nie jest jeszcze wystarczająco rozpoznane. Technologia jest trudna z powodu dużej ,,wrażliwości" betonu samozagęszczalnego na wszelkie zmiany jakościowe i ilościowe jego składników. Dodatek włókien przyczynia się do poprawy niektórych właściwości stwardniałych kompozytów, ale stanowi o pogorszeniu charakterystyk na etapie układania i zagęszczania. W artykule przedstawiono wyniki badań, dotyczące wpływu włókien polipropylenowych na wybrane właściwości betonu samozagęszczalnego. Stwierdzono, że mały dodatek włókien nie powoduje zmian we właściwościach reologicznych mieszanki betonowej. Pewne niewielkie niekorzystne zmiany wystąpiły podczas samoodpowietrzenia, skutkując nieznacznym wzrostem porowatości mieszanki betonowej i nasiąkliwości betonu. Zastosowanie włókien spowodowało zmniejszenie skurczu betonu i nie przyczyniło się do zmniejszenia wytrzymałości betonu na ściskanie.

Słowa kluczowe: beton samozagęszczalny, włókno polipropylenowe, skurcz, nasiąkliwość, wodoprzepuszczalność, wytrzymałość na ściskanie

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