TECHNICAL TRANSACTIONS 5/2019
CIVIL ENGINEERING

DOI: 10.4467/2353737XCT.19.055.10579
SUBMISSION OF THE FINAL VERSION: 15/04/2019

Adrian Chajec orcid.org/0000-0001-5329-9534
adrian.chajec@pwr.edu.pl

Kamil Krzywiński orcid.org/ 0000-0002-5562-9602
Faculty of Civil Engineering, Wroclaw University of Science and Technology

Krzysztof Ostrowski orcid.org/0000-0001-5047-5862
krzysztof.ostrowski.1@pk.edu.pl
Institute of Building Materials and Structures, Cracow University of Technology

Łukasz Sadowski orcid.org/0000-0001-9382-7709
Faculty of Civil Engineering, Wroclaw University of Science and Technology

The influence of polypropylene fibres on the properties of fresh and hardened concrete

Wpływ dodatku włókien polipropylenowych na właściwości mieszanki betonowej oraz betonu stwardniałego

Abstract

The purpose of the article is to determine the effect of the addition of polypropylene fibres on the properties of concrete mixtures and hardened concrete. To this end, both destructive and non-destructive tests were conducted. The concrete mixture tests included the testing of the consistency, air content and bulk density of the concrete mixture. Investigations of hardened concrete were based on the determination of compressive strength by destructive tests, sclerometer and ultrasonic methods and tensile strength in bending tests. All tests were performed for seven series of concrete mixtures, differing in their fibre content. The results showed that the addition of polypropylene fibres to the concrete mixture causes changes in consistency, increases air content, and does not increase the compressive and tensile strength of concrete. It was also observed that the addition of polypropylene fibres does not cause significant changes in the bulk density of the concrete mix.

Keywords: fibre-reinforced concrete, polypropylene fibres, dispersed reinforcement, fresh concrete mixture, hardened concrete

Streszczenie

Tematem artykułu jest określenie wpływu dodatku włókien polipropylenowych na właściwości mieszanki betonowej oraz betonu stwardniałego. W tym celu przeprowadzono badania świeżej mieszanki betonowej oraz betonu stwardniałego (niszczące oraz nieniszczące). W skład badań mieszanki betonowej wchodziły: badanie konsystencji mieszanki betonowej, badanie zawartości powietrza w mieszance betonowej, badanie gęstości objętościowej mieszanki betonowej. Badania betonu stwardniałego opierały się na pomiarze wytrzymałości betonu na ściskanie, wytrzymałości betonu na rozciąganie przy zginaniu, wytrzymałości betonu na ściskanie metodą sklerometryczną oraz wytrzymałości betonu na ściskanie metodą ultradźwiękową. Wszystkie badania zostały wykonane dla siedmiu serii mieszanek betonowych, różniących się od siebie zawartością włókien. Dodatek włókien polipropylenowych do mieszanki betonowej powoduje zmiany jej konsystencji oraz podwyższenie w niej zawartości powietrza. Włókna polipropylenowe nie powodują istotnych zmian gęstości objętościowej mieszanki betonowej.

Słowa kluczowe: fibrobeton, włókna polipropylenowe, zbrojenie rozproszone, mieszanka betonowa, beton stwardniały

1. Introduction

Reinforcement in the form of fibre additives has been used in concrete mixtures for a long time [1, 5, 6]. The basic purpose of adding fibres to the cement matrix is to provide homogeneous properties, regardless of the direction of load [3, 4]. Steel fibres are the most commonly used [22, 24, 25], although polypropylene fibres are increasingly added to the concrete mixture. The characteristics of the changes implemented in the properties of concrete mix and hardened concrete caused by the addition of fibres is a complicated phenomenon and depends upon many factors [1, 3, 4, 8, 10, 23, 25].

The properties of the concrete mix influence its suitability for forming parts of structural elements in building structures [1, 5, 7, 9, 14, 22]. In this context, several technological regimes introduce a number of requirements for the properties of a concrete mixture, including those with the addition of fibres, such as: adequate consistency, limited air content, a specific volume density [5, 14–17]. In order to understand the impact of fibre addition on the properties of a concrete mixture, those properties should be examined [8, 13, 17].

The use of fibres for the sole purpose of improving the mechanical properties of concrete is the most common reason for their addition [4, 8, 14, 16]. Steel fibres can affect the mechanical properties of hardened concrete; this has been proven many times [4, 5]. The present research was conducted to determine the impact of polypropylene fibres on the properties of both concrete mix and hardened concrete.

2. Materials

2.1. Methodology

In order to determine the impact of polypropylene fibres on the properties of both concrete mixture and hardened concrete, a study was designed consisting of two main stages: fresh concrete mix tests and hardened concrete tests (after 28 days of curing). The concrete mixture tests included: consistency tests using the slump test (in accordance with PN-EN 12350-2); air content tests (according to PN-EN 12350-7); bulk density tests (according to PN-EN 12350-6). The tests carried out on hardened-concrete samples were: compressive strength tests of concrete (in accordance with PN-EN 12390-3); concrete tensile strength tests in bending (in accordance with PN-EN 12390-5); concrete compressive strength tests using a sclerometric method (according to [2]); examination of the compressive strength of concrete using ultrasound (according to [13]). The tests were performed for seven series of concrete samples (Table 1) with different proportions of fibres.

Table 1. Fibre content for each concrete series

Number of series	Fibre content [%]
FP0	0.0
FP1.5	1.5
FP2.0	2.0
FP2.5	2.5
FP3.0	3.0
FP3.5	3.5
FP4.0	4.0

3. Components of concrete mixture

All mixes were prepared using cement type III 42.5 (320 kg/m^3, Hranice, Czech Republic), sand ϕ0–2 mm (700 kg/m^3, Byczeń, Poland), gravel ϕ2–8 mm (443 kg/m^3, (Byczeń, Poland), gravel ϕ8–16 mm (700 kg/m^3, Byczeń, Poland). Superplasticiser Pantarhit FM (3.84 kg/m^3) were used to obtain workability of the concrete mixture. The amount of the polypropylene fibres was since 0 to 4.0 kg/m^3. The concrete mixtures were made with the same proportions of ingredients and a constant water/cement ratio w/c = 0.5.

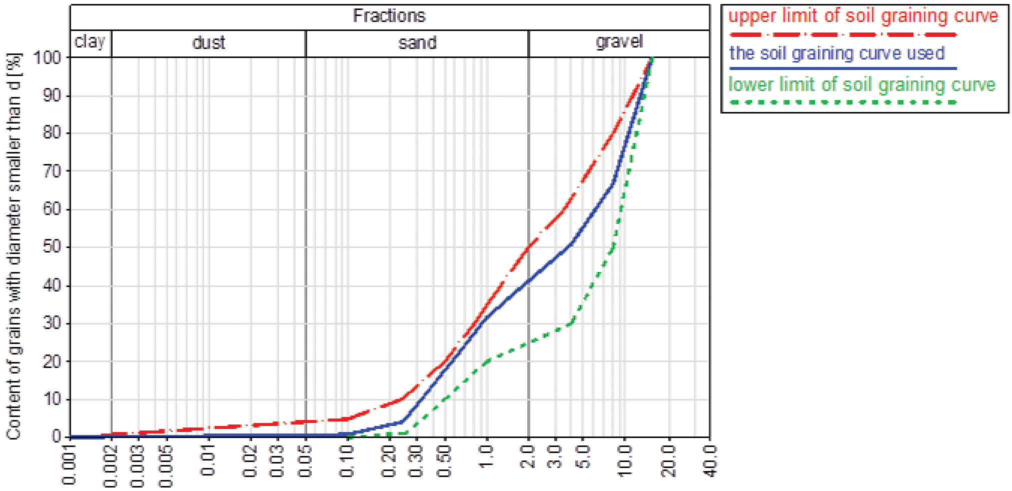

Fig. 1. Grain curve of mixture of aggregates used to make the concrete mixture in relation to the limit aggregate curves described in the standard [3]

A C25/30 class of concrete was designed. Fig. 1 shows the grain curve of the mixture of aggregates used in the concrete mixture. Polypropylene fibres with a length of 48 mm and a diameter of 0.6 mm were used for the tests. The manufacturer states that the average tensile strength of these fibres is 600 MPa, while the Young's Modulus is 5 GPa.

3.1. Preparation of specimens

The dry ingredients (with the specified amount of fibres) were mixed with 1/3 of the water for 30 seconds. The rest of the water was then added to the superplasticiser and the ingredients were mixed for 60 seconds. After mixing, the concrete mixture was tested. The mix used for the tests was then added to the remaining part in the mixer and mixed for 30 seconds. Following this, the concrete mixture was poured into previously prepared forms. After 24 hours, the samples were removed from the moulds and placed in containers with water for 28 days.

Fig. 2. Preparation of the concrete mixture: a) mixing of dry ingredients; b) weighing of the fibers; c) pouring concrete into the forms

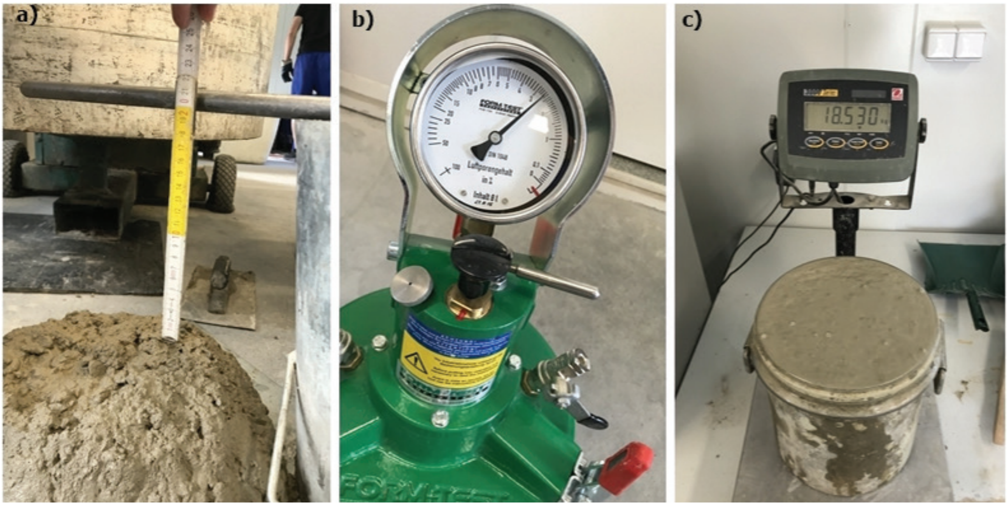

Fig. 3. Testing of the concrete mixture: a) slump test of the concrete mixture; b) air content test of the concrete mixture; c) bulk density test of the mixture

Fig. 4. Testing of the hardened concrete: a) sclerometric method; b) destructive test – uniaxial compression test; c) testing of concrete tensile strength under bending

4. Results and discussion

4.1. Fresh concrete mixture properties

Fig. 5 presents the results of the testing of the consistency of the concrete mix using the slump test (Fig. 3a) for the different proportions of fibre. Fig. 5 shows that the addition of polypropylene fibres to the concrete mixture results in a significant (about 10 cm) change in the slump value of the concrete mixture. This is due to the large surface area of the fibres added to the concrete mix, which requires a cement paste environment. This causes a reduction in the amount of remaining cement mortar in the concrete mixture and consequently, a change in the consistency to a more dense plastic. It should also be noted that the addition of polypropylene fibres results in changes in the consistency of the concrete mixture from S4 to S3. In addition, a polypropylene fibre content above 3.0 kg/m^3 reduces the consistency class to S2.

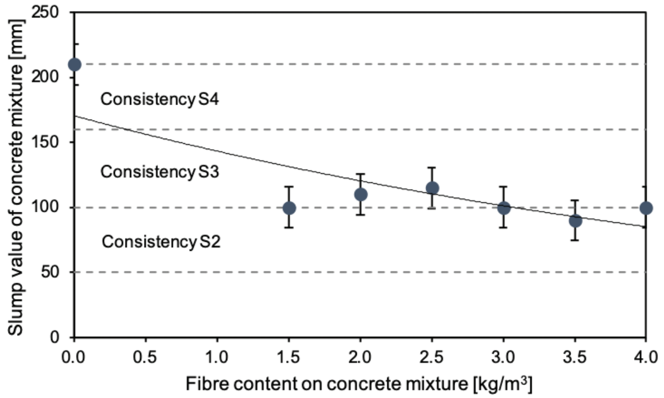

Fig. 5. Slump value of concrete mixture for the different proportions of polypropylene fibres

Fig. 6 presents the results of the air content test in a concrete mix dependent upon the polypropylene fibre content (Fig. 3b).

It can be seen from Fig. 6 that as the content of polypropylene fibres in the concrete mix increases, the air content also increases. The presence of fibre influences the heterogeneity in the concrete mixture and increases the number of voids.

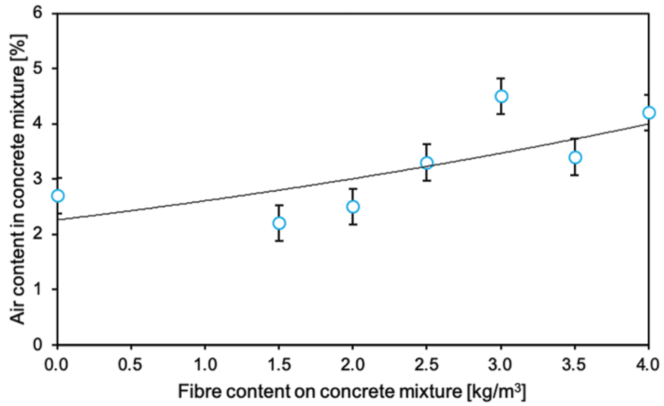

Fig. 6. Dependence of air content in concrete mix on the content of polypropylene fibres

Fig. 7 presents the results of the volume density test of the concrete mix dependent upon the content of polypropylene fibres (Fig. 3c).

It can be seen from Fig. 7 that the addition of polypropylene fibres has no significant effect on the bulk density of the concrete mix.

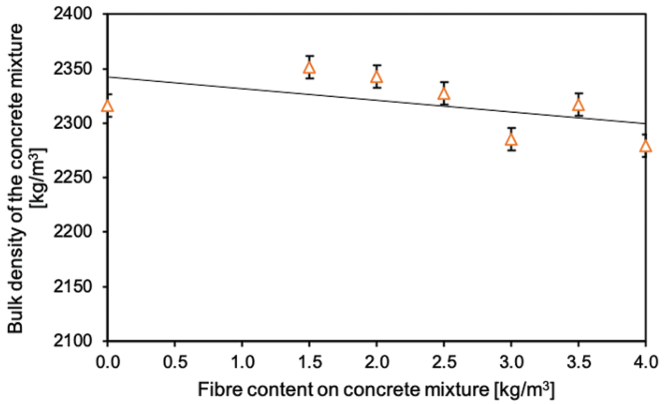

Fig. 7. Dependence of the bulk density of concrete mix on the content of polypropylene fibres

4.2. Testing of hardened concrete

Table 2 presents the results of tests of the compressive strength of concrete using ultrasound.

Table 2. The results of the compressive strength test of concrete using the ultrasound method

Concrete mix number	Sample number	Average velocity [m/s]	Compressive strength [Mpa]	Standard deviation [-]	Average Compressive strength [Mpa]
FP0	S1	4752.11	52	5.39	52.00
	S2	4632.57	50		
	S3	4802.84	54		
FP1.5	S1	4306.23	38		37.33
	S2	4298.58	38		
	S3	4257.39	36		
FP2.0	S1	4429.14	44		44.00
	S2	4407.68	44		
	S3	4424.88	44		
FP2.5	S1	4336.46	38		37.33
	S2	4299.79	36		
	S3	4335.43	38		
FP3.0	S1	4407.55	42		40.67
	S2	4468.94	44		
	S3	4258.09	36		
FP3.5	S1	4491.26	50		44.67
	S2	4362.28	42		
	S3	4348.72	42		
FP4.0	S1	4483.38	48		47.33
	S2	4403.49	46		
	S3	4439.94	48		

Fig. 8 shows the correlation curve used to determine the compressive strength of concrete using the sclerometric method.

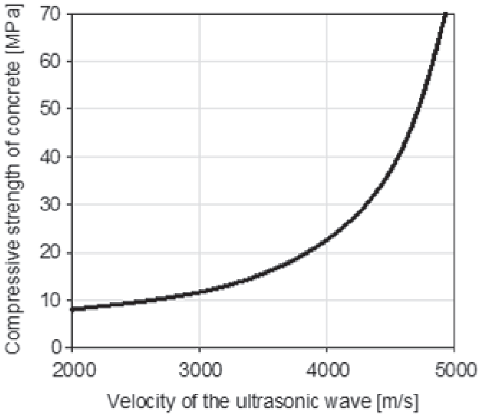

Fig. 8. Dependence of the compressive concrete strength on ultrasonic wave speed, based on [13]

Table 3 presents the results of concrete compressive strength tests using a sclerometric method.

Table 3. The results of the concrete compressive strength test using a sclerometric method

Specimen	L1	L2	L3	L4	L5	$\overline{L}$	R according to ITB210 [MPa]	$\overline{Rc}$ [Mpa]
FP0-1	31	34	30	28	34	31	18.44	
FP0-2	34	39	34	35	33	35	25.60	23.21
FP0-3	36	34	36	36	34	35	25.60	
FP1.5-1	32	32	30	33	34	32	20.10	
FP1.5-2	35	33	31	30	33	32	20.10	20.10
FP1.5-3	35	33	32	32	28	32	20.10	
FP2.0-1	34	33	32	34	32	33	21.85	
FP2.0-2	34	34	38	38	39	37	29.67	27.07
FP2.0-3	36	40	34	38	39	37	29.67	
FP2.5-1	36	36	34	38	32	35	25.60	
FP2.5-2	33	31	30	29	31	31	18.44	20.82
FP2.5-3	30	32	30	32	31	31	18.44	
FP3.0-1	38	34	32	33	34	34	23.69	
FP3.0-2	31	31	31	29	31	31	18.44	19.66
FP3.0-3	32	30	30	29	30	30	16.85	
FP3.5-1	32	32	35	31	30	32	20.10	
FP3.5-2	35	33	35	38	32	35	25.60	23.77
FP3.5-3	34	32	34	38	35	35	25.60	
FP4.0-1	34	30	31	34	30	32	20.10	
FP4.0-2	34	33	31	33	34	33	21.85	20.69
FP4,.0-3	36	32	30	31	33	32	20.10	

Fig. 9 shows the correlation curve used to determine the compressive strength of concrete using the sclerometric method.

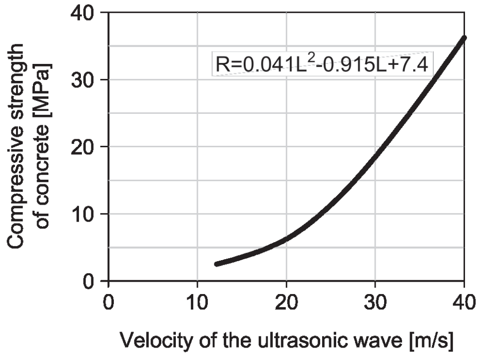

Fig. 9. L-R dependence curve according to ITB210 instructions, own elaboration based on [2]

Fig. 10 presents the results of concrete compressive strength tests using various methods: ultrasonic, sclerometric and destructive, dependent upon the content of polypropylene fibres.

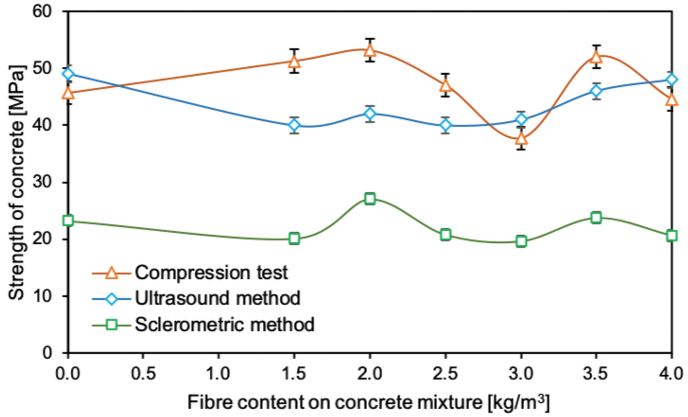

Fig. 10. The compressive strength of concrete, determined by different methods, dependent upon the content of polypropylene fibres

It can be seen from Fig. 10 that different values of the compressive strength were obtained depending upon the method according to which it was determined. The most accurate method is the destructive method. Attention should be paid to the similar course of strength diagrams pertaining to the sclerometric method and the destructive method; however, the values of determined strengths vary considerably. This is due to the fact that the sclerometric method determines the surface resistance of concrete compressive strength and is treated as an illustrative test. In turn, destructive testing is a more accurate method to assess the strength of concrete. Values obtained for concrete strength by the ultrasonic and destructive methods are similar to each other. No clear dependence of the compressive strength of concrete on the polypropylene fibre content was observed.

Fig. 11 presents the results of the tests of concrete tensile strength under bending dependent upon the content of polypropylene fibres (Fig. 4c).

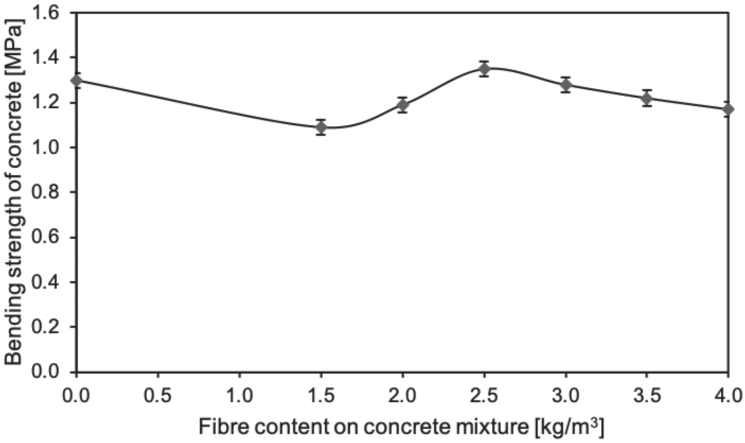

Fig. 11. Tensile strength of concrete in the bending test dependent upon the content of polypropylene fibres

It can be seen from Fig. 11 that the addition of polypropylene fibres does not significantly affect the concrete tensile strength under bending. The graph also does not show a clear relationship between the concrete tensile strength under bending and the content of polypropylene fibres.

5. Conclusions

The following conclusions may be drawn from the work presented in this paper:

- The consistency of a concrete mix depends on the proportion of polypropylene fibres.
- The air content in a concrete mix depends on the density of polypropylene fibres. Along with the increase of fibre content in the concrete mix, the air content also increases.
- The addition of polypropylene fibres to the concrete mix does not have a significant impact on its bulk density.
- The addition of polypropylene fibres to concrete does not increase its compressive strength.
- The tested value of the compressive strength of concrete depends on the method which was employed to determine it.
- The addition of polypropylene fibres does not increase the tensile strength of concrete during bending.

References

[1] ACI Committee 544, *Measurement of Properties of Fiber Reinforced Concrete*, ACI, 1999.

[2] Jamroży Z., *Beton i jego technologie*, Wydawnictwo Naukowe PWN, Warszawa 2005.

[3] Piotrowski T., Świątek-Żołyńska S., *Beton posadzkowy – wymagania i odpowiedzialność za jakość zgodnie z PN-EN 206*, Materiały Budowlane 9, 2017.

[4] Glinicki M.A., *Beton ze zbrojeniem strukturalnym*, XXV Ogólnopolskie warsztaty pracy projektanta konstrukcji, Szczyrk, 10–13.03.2010, 279–308.

[5] Jamroży Z., *Betony ze zbrojeniem rozproszonym: co projektant konstrukcji wiedzieć powinien*, Materiały XVII Ogólnopolska Konferencja Warsztaty Pracy Projektanta Konstrukcji, Ustroń 2002.

[6] Chandler J.W.E., *Design of floors on ground*, Cement and Concrete Association, London 1982.

[7] Kırgız M.S., *Effect of mineralogical substitution raw material mixing ratio on mechanical properties of concrete*, ZKG International 10, 2018, 30–41.

[8] Aslani F., Gedeon R., *Experimental investigation into the properties of self-compacting rubberised concrete incorporating polypropylene and steel fibers, Structural Concrete*, Structural Concrete 20, 2019, 267–281.

[9] Kırgız M.S., *Fresh and hardened properties of green binder concrete containing marble powder and brick powder*, European Journal of Environmental and Civil Engineering 20 (sup1), 2016, 64–101.

[10] Kırgız M.S., *Green cement composite concept reinforced by graphite nano-engineered particle suspension for infrastructure renewal material*, Composites Part B: Engineering 154, 2018, 423–429.

[11] Simões T., Octávio C., Valença J., Costa H., Dias-da-Costa D., Júlio, E., *Influence of concrete strength and steel fibre geometry on the fibre/matrix interface*, Composites Part B: Engineering 122, 2017, 156–164.

[12] ITB. Instrukcja ITB nr 209: *Instrukcja stosowania metody ultradźwiękowej do nieniszczącej kontroli jakości betonu w konstrukcji*, Warszawa: ITB, 1977.

[13] ITB. Instrukcja ITB nr 210/1977: *Instrukcja stosowania młotków Schmidta do nieniszczącej kontroli jakości betonu w konstrukcji*, Warszawa: ITB, 1977.

[14] PN-EN 12350-2:2011: *Badania mieszanki betonowej. Część 2: Badanie konsystencji metodą opadu stożka.*

[15] PN-EN 12350-6:2011: *Badania mieszanki betonowej. Część 6: Gęstość.*

[16] PN-EN-12350-7:2011: *Badania mieszanki betonowej. Część 7: Badanie zawartości powietrza – Metody ciśnieniowe.*

[17] PN-EN 12390-2:2011: *Badania betonu. Część 2: Wykonywanie i pielęgnacja próbek do badań wytrzymałościowych.*

[18] PN-EN 12390-3:2011: *Badania betonu. Część 3: Wytrzymałość na ściskanie próbek do badań.*

[19] PN-EN 12390-5:2011: *Badania betonu. Część 5: Wytrzymałość na zginanie próbek do badań.*

[20] PN-EN 12504-4:2005: *Badania betonu. Część 4: Oznaczanie prędkości fali ultradźwiękowej.*

[21] PN-EN 12620+A1:2010: *Kruszywa do betonu*.
[22] Hajduk P., *Projektowanie i ocena techniczna betonowych podłóg przemysłowych*, Wydawnictwo Naukowe PWN, Warszawa 2018.
[23] Kırgız M.S., *Steel Fibre and Shotcrete Concrete*, Bachelor of Science Thesis, University of Gazi, Faculty of Technical Education, Department of Construction, Ankara 1997, T.R.
[24] Xie X., Kang X., Jin Y., Cai J., *The Effect of Mechanical Performance on PP Fiber to Polymer Mortar*, In IOP Conference Series: Earth and Environmental Science 128(1), 2018, 012038.
[25] Krzywiński K., Chajec A., Sadowski Ł., *The effect of the concentration of steel fibres on the properties of industrial floors*, Technical Transactions 4, 2019.
[26] Hoła J., Sadowski Ł., Hoła A., *Ultradźwiękowe badania wytrzymałości na ściskanie posadzek cementowych wzdłuż ich grubości*, Materiały Budowlane 10, 2017, 44–46.
[27] Ponikiewski T., *Wpływ dodatku włókien polipropylenowych na właściwości reologiczne mieszanek na spoiwach cementowych*, Zeszyty Naukowe Politechniki Śląskiej. Budownictwo 2001, 381–390.

If you want to quote this article, its proper bibliographic entry is as follow: Chajec A., Krzywiński K., Sadowski Ł., Ostrowski K., *The influence of polypropylene fibres on the properties of fresh and hardened concrete*, Technical Transactions, Vol. 5/2019, pp. 71–82.