TECHNICAL TRANSACTIONS 4/2019
CIVIL ENGINEERING
DOI: 10.4467/2353737XCT.19.047.10359
SUBMISSION OF THE FINAL VERSION: 30/03/2019

Kamil Krzywiński orcid.org/0000-0002-5562-9602
kamil.krzywinski@pwr.edu.pl
Adrian Chajec orcid.org/0000-0001-5329-9534
Łukasz Sadowski orcid.org/0000-0001-9382-7709
Faculty of Civil Engineering, Wroclaw University of Science and Technology

The effect of the concentration of steel fibres on the properties of industrial floors

Wpływ zawartości włókien stalowych na właściwości posadzek przemysłowych

Abstract

This paper presents the results of a series of experiments on samples made of steel fibre reinforced concrete. The investigated samples were made with different concentrations of steel fibres ranging from 20.0 to 32.5 kg/m3. Twenty-one cubic samples (15 x 15 x 15 cm) and fourteen cuboid samples (15 x 15 x 60 cm) were used for this investigation. The article focusses on the effect of the concentration of steel fibres on the properties of industrial floors. For this purpose, both destructive and non-destructive methods were used and compared. As a result of this study, it has been proved that compressive and flexural tensile strength are lower with increasing air content and decreasing density of concrete. Moreover, it was found that there is a correlation between ultrasonic pulse velocity and rebound hammer results which together can be used to estimate the compressive strength of steel fibre reinforced concrete.

Keywords: steel fibres, industrial floors, non-destructive methods

Streszczenie

W niniejszym artykule przedstawiono wyniki serii eksperymentów wykonanych na próbkach z betonu zbrojonego włóknami stalowymi. Badane próbki zbrojone były różną zawartością włókien stalowych od 20.0 do 32.5 kg/m3. Do badań użyto 21 sześciennych (15 x 15 x 15 cm) i 14 prostopadłościennych (15 x 15 x 60 cm) próbek betonowych. W artykule skupiono się na zbadaniu wpływu zawartości włókien stalowych na właściwości posadzek przemysłowych. Do badań zastosowano i porównano metody niszczące oraz nieniszczące. W rezultacie udowodniono, że wytrzymałość na ściskanie i rozciąganie przy zginaniu zmniejsza się wraz ze wzrostem zawartości powietrza i malejącą gęstością betonu. Ponadto stwierdzono, że istnieje korelacja między wynikami ultradźwiękowymi i sklerometrycznymi, które mogą być wykorzystane do oszacowania wytrzymałości na ściskanie betonu zbrojonego włóknami stalowymi.

Słowa kluczowe: włókna stalowe, posadzki przemysłowe, metody nieniszczące

1. Introduction

The influence of the steel fibres and the morphology of coarse aggregate on the structural concrete is well known [1; 7; 16; p. 1372]. However, steel fibre reinforced concrete has recently also become popular in industrial floors. This is mainly due to the fact that it enables a reduction in the construction time and protects the floor against shrinkage cracking. In both the design and repair stages of industrial and public structures they can be also used for better protection of concrete industrial floors against extreme loading conditions, including terrorist or mass-casualty attacks, natural hazards and disasters. This kind of reinforcement has been widely used over recent decades [11] and its use has significantly increased in industrial floors, roads, bridges, columns, parking areas, tunnels, and airport runways [10; 13, p. 551; 14; 18]. Steel fibre reinforcement is also used as a method for providing better crack development control and as a result can reduce the number of joints [2, 21]. Steel fibre reinforcement can greatly increase the energy adsorption and impact strength of concrete.

In this study, steel fibres were used as reinforcement to reduce shrinkage cracks, but there are also other materials which are used as fibres in concrete structures, for example polypropylene. In the case of polypropylene fibres, the number of fibres added to the concrete mixture is typically higher than the number of steel fibres, because both the single polypropylene fibre weight and Young's modulus are lower than in the case of steel. Therefore, because of different properties of polypropylene and steel fibres, there are differences between the concentrations used in concrete mixtures.

Most of the research on fibre reinforcement are focused on fibre type and geometry, and some include considerations on the subject of content by volume [5, 15]. A few researchers have also investigated the effects of concrete type [2, 6, 9, 12]. However, the task of evaluating steel fibre cement in concrete used to make industrial floors is difficult. Steel fibre reinforced concrete is mostly formed horizontally when constructing industrial floors on the ground and it is assumed its mechanical strength is not identical in all directions [17]. The impact of the air content and the density of hardened concrete on the properties of this kind of industrial floor is also unknown. Considering the above, the article will focus on investigating the effect of the content of steel fibres on the properties of industrial floors. For this purpose, both destructive and non-destructive methods have been used and compared.

2. Materials and Methods

2.1. Methodology

The paper divides the experimental study into two parts. The first part concerns the properties of fresh concrete and tests for second part was performed on hardened concrete after twenty-eight days of curing. Tests in the first part of the investigation were performed on seven mixtures and thirty-five specimens were used for the second part of the study.

The first part of the study includes measurements of fresh concrete workability using a concrete slump test [27, 29], the temperature of the ready concrete mixture and the relative humidity in the laboratory during the study, and the density and air content [23, 30] of the fresh concrete. The second part of the study includes measurements of the density of hardened concrete, non-destructive compressive strength testing using ultrasonic pulse velocity [25] and rebound hammer [26, 28], destructive compressive strength testing using the compression-testing machine [22] and flexural tensile strength testing using loading apparatus [24, 31].

2.2. Concrete mixture

The proportions of the concrete mixture components should be suitable for the planned loads or the directed environment. The concrete was designed in such a way as to be used as the main floor layer. The components and their proportions used for this study are presented in Table 1.

Table 1. Concrete mixture recipe

Components	Quantity [kg/m^3]	Volume [dm^3]
cement (CEM III, Hranice Czech Rep.)	320	106.70
water	158	158.00
aggregate 0-2 mm (Byczeń, Poland)	700	267.20
aggregate 2-8 mm (Byczeń, Poland)	443	170.40
aggregate 8-16 mm (Byczeń, Poland)	700	269.40
superplasticiser (Pantarhit FM 1.2%)	3.84	3.34

The water-binder ratio was 0.5. The designed concrete class was C25/30. In this research, CEM III/A 42.5 N cement was used. Its properties and chemical content are summarised in Table 2.

Table 2. Selected properties of cement

Property	Minimum	Maximum
2-day compressive strength [MPa]	13.73	21.53
28-day compressive strength [MPa]	53.56	61.52
2-day flexural tensile strength [MPa]	3.05	4.51
28-day flexural tensile strength [MPa]	7.85	11.78
Na_2O content [%]	0.230	0.410
K_2O content [%]	0.550	0.860
SO_3 content [%]	2.420	2.650
Cl content [%]	0.028	0.085

The aggregate grain size curve for concrete used in this study is presented in Fig. 1.

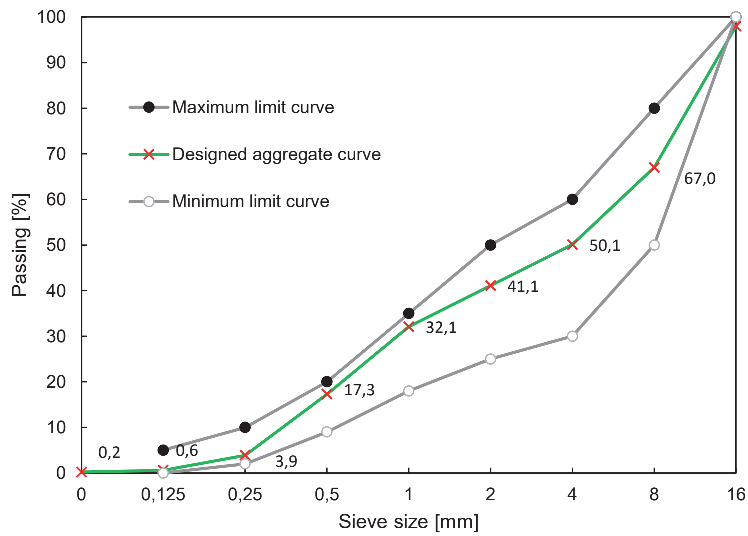

Fig. 1. The aggregate grain size curve

The Pantarhit FM superplasticiser (Ha-Be, Poland) was used in the concrete mixture at an amount equal to 1.2% of the mass of the cement. This superplasticizer is based on naphthalene sulfonate. Table 3 shows the basic properties of this superplasticiser.

Table 3. The properties of the used superplasticiser

Properties	Description
density [g/cm^3]	1.15
pH [-]	6.0
chloride content [%]	< 1.0
alkali content [%]	< 4.0

2.3. Steel fibres

The properties of the added steel fibres (BAUTECH, Poland) to the concrete mixture are shown in Table 4.

The commonly used steel fibre dosing values are between 18–34 kg/m^3 for industrial floors in real structures. Therefore, samples with dosing from 20.0 kg/m^3 to 32.5 kg/m^3 of steel fibres at 2.5 kg/m^3 intervals were prepared for this research (see Fig. 2). The samples were numbered from 2 to 7. In order to be used as a control, one sample was prepared without steel fibres. This control sample is denoted by number 1.

Table 4. The properties of steel fibres

Property	Description
length [mm]	50
diameter [mm]	1.0
average tensile strength [MPa]	1,100
Young module [GPa]	180
pieces / kg [pc/kg]	3,200
total fibre length / kg [m/kg]	160

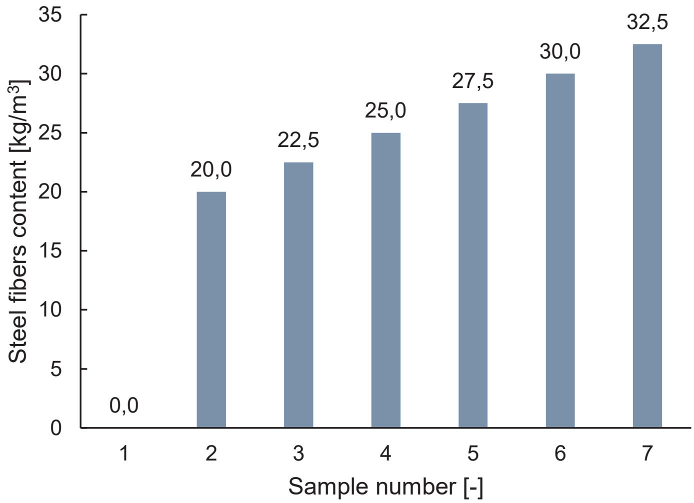

Fig. 2. Steel fibre content for each sample

2.4. Sample preparation

The preparation of samples began with the mixing of aggregates and steel fibres (dosing dependent on sample number) with 1/3 volume of required water for thirty seconds. The binder was then added to the rest of water and mixed for sixty seconds; during mixing, the superplasticiser was added. After mixing, the prepared fresh concrete was tested to measure its properties. The average temperature of the fresh concrete during the study was 23.3°C (± 3.2°C). The average air temperature in the laboratory was 24.6°C (± 3.6°C) together with air humidity of 47.3% (± 10%). Some of the preparation steps are shown in Fig. 3.

Cube samples measuring 15 x 15 x 15 cm were prepared in polymer forms and cuboid samples 15 x 15 x 60 cm were prepared in steel forms. After twenty-four hours of curing, the samples were placed in a special container with water inside. Before compressive and flexural tensile strength testing, the samples were tested using non-destructive tests.

Fig. 3. Sample preparation process

2.5. Properties of fresh concrete

2.5.1. Concrete slump test

The concrete slump test measures the workability of fresh concrete using a special cone mould which is described in [27, 29]. Before the test, the internal surface of the mould was cleaned and had oil applied. The mould was placed on a smooth horizontal non-porous steel base plate. The form was then filled with the prepared fresh concrete in three approximately equal layers. Each layer was tamped using the rounded end of the tamping rod in a uniform manner. For the subsequent layers, the tamping penetrated into the underlying layers. The excess concrete was removed, and the surface was levelled with a trowel. The mould was raised from the concrete immediately and slowly in a vertical direction without stopping. The slump was then measured as the difference between the height of the mould and that of height point of the specimen being tested (Fig. 4a).

2.5.2. Density

Fresh concrete density was calculated using the weight measuring device which is shown in Fig. 4b. The pail was filled with the fresh concrete in a few layers which were tamped using a concrete vibrator. Hardened concrete density was calculated in a similar manner but without the need for the tamping process. The samples were drawn out from the special container with water inside after twenty-eight days of curing and were then left for two hours for initial drying before being weighed.

2.5.3. Air content

To verify the air content of freshly mixed concrete, the pressure method according to [23, 30] was used. This method is preferable due to it providing relatively fast results. Initially, the fresh concrete was filled and tamped in a similar manner as described in 2.5.2. Next the top

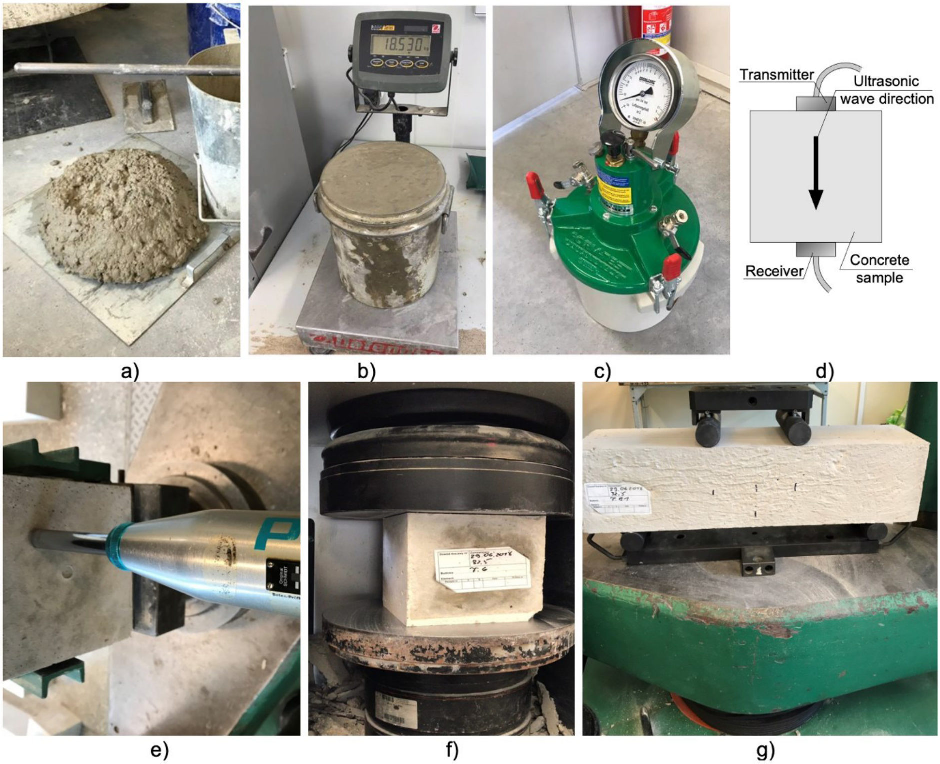

Fig. 4. Fig. 4. Performed tests on fresh and hardened concrete: a) the slump height measurement; b) fresh concrete weight measurements; c) pressure inside of the air-content test device; d) scheme of ultrasonic pulse velocity direct method e) rebound hammer test; f) compressive strength test; g) flexural tensile strength test

of the air-content test device was closed. Then, the air gap between the top of the concrete surface and the underside of the top of air meter with water was filled. The top of the air meter was then pressurised with the built-in hand pump until it zeroed out. After a stabilisation period, the pressure in the top was released and the air-void content on the dial on the top of the meter was read (Fig. 4c).

2.6. Properties of hardened concrete

2.6.1. Compressive strength

2.6.1.1. Ultrasonic pulse velocity (UPV)

The UPV is an effective non-destructive testing method for the quality control of concrete materials (Fig. 4d). Using this method, it is possible to detect damage in the structural components of existing buildings. The ultrasonic pulse velocity method has recently been successfully used by Ongpeng et al. [4] for concrete reinforced with short steel fibres. In this research, tests were conducted according to [25]. In generalization travel time of ultrasonic waves reflects internal condition of tested sample. Lower wave speeds indicate that the concrete is of poor quality and higher wave speeds indicate that the concrete is of good quality. To measure ultrasonic pulse velocity in this study, the Proceq model was used: Pundit-lab. The ultrasonic pulse velocity measurement results were measured with one configuration of transducers – direct transmission.

2.6.1.2. Rebound hammer test

The rebound hammer test is another non-destructive method which was used in this research to define compressive strength (Fig. 4e) according to [26, 28]. This test measures the extent of rebound, which is a measure of surface hardness. This value is measured when the plunger of the rebound hammer is pressed against the surface of the concrete; a spring controlled mass with a constant energy then strikes the concrete surface and rebounds. The measured value of the rebound corresponds to concrete strength. To measure rebound value in this study, the Proceq Original Schmidt was used. The measurements were performed on samples which were constantly loaded with $0.1f_{ck}$ in the compression testing machine. The points where the rebound value was measured by the hammer were located at least 3 cm from the edge of the sample.

2.6.1.3. Compressive strength test

The compressive strength test is a standard test method [22] which was performed using a compression testing machine on 15 x 15 x 15 cm dimension samples after twenty-eight days of curing. The average compressive strength was calculated on the basis of results from three tests on cube forms. The destructive compressive strength test method is presented in Fig. 4f.

2.6.1.4. Flexural tensile strength test

The flexural test indirectly evaluates the tensile strength of concrete; it tests the ability of a concrete beam to withstand failure under bending. The tests were performed on two cuboid samples 10 x 10 x 60 cm after 28 days of curing for every concentration of steel fibres (Fig. 4g) according to [24, 31].

3. Test results and analysis

3.1. Properties of fresh concrete

3.1.1. Concrete slump test

The average slump height decreases with increases in the concentration of steel fibres (Fig. 5). All samples with steel fibres result in lower slump heights than samples without steel fibres. The water to binder ratio for each mix was constant at 0.5; thus, it is possible that water molecules could accumulate on the surface of steel fibres, which would explain the impact that the concentration of steel fibres has on slump height.

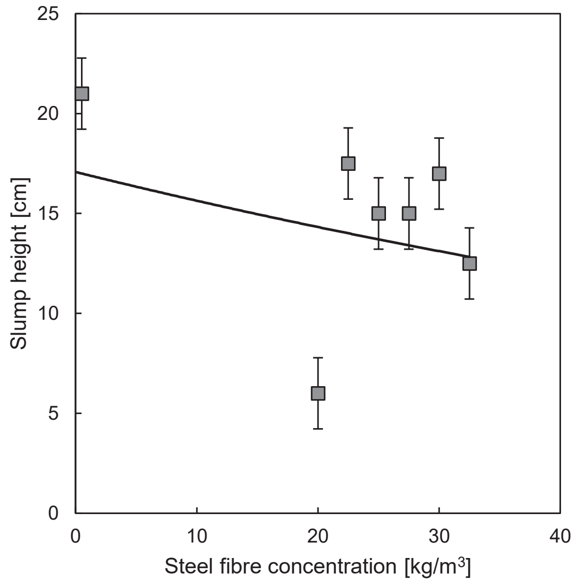

Fig. 5. Fresh concrete slump test results

3.1.2. The density

The density for all of the samples is in the range of approximately 2,300–2,350 kg/m^3 (Fig. 6). It appears that the steel fibres don't have any impact on the density of fresh concrete.

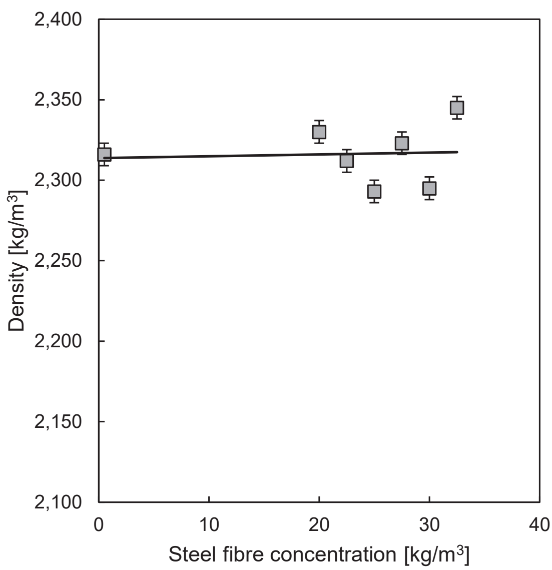

Fig. 6. The density of fresh concrete

3.1.3. Air content

The air content in the sample without steel fibres is significantly lower than in the samples with steel fibres. The air content in the fresh concrete (Fig. 7) increases with the concentration of steel fibres. The same tamping time using the concrete vibrator for each mixture could be responsible for increasing the air in the concrete; this is an undesirable phenomenon in concrete structures.

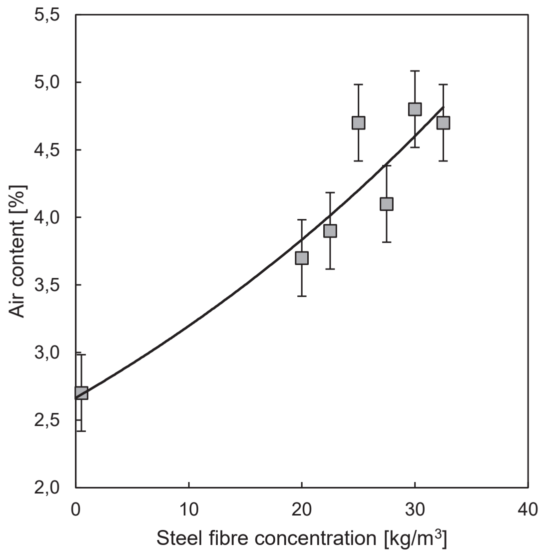

Fig. 7. Air content in fresh concrete

3.2. Properties of hardened concrete

3.2.1. The density

The sample without steel fibres and the sample with the lowest concentration of steel fibres (20 kg/m^3) have the highest density results (Fig. 8). Analysing the results from Fig. 7, the lower values of density for the samples with steel fibres > 20 kg/m^3 are probably due to the evaporation of water which didn't take part in the hydration process.

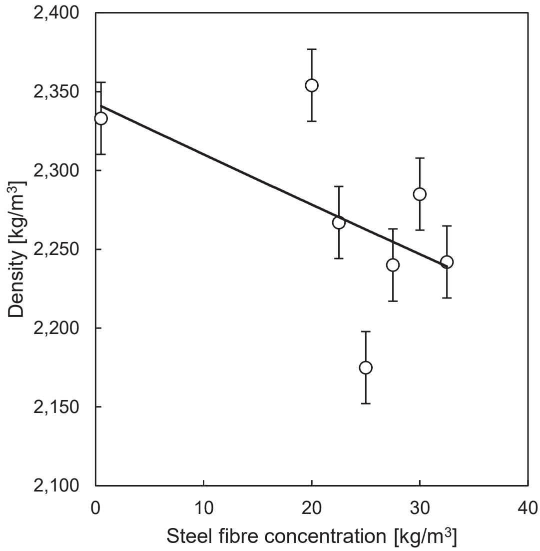

Fig. 8. Hardened concrete density

3.2.2. Compressive strength

In this research, compressive strength was investigated by three different methods, one destructive and two non-destructive (Fig. 9). The ultrasonic pulse velocity method has mostly similar results. The compression test and the rebound hammer compressive strength curves have similar shapes; however, the non-destructive method records have around 20

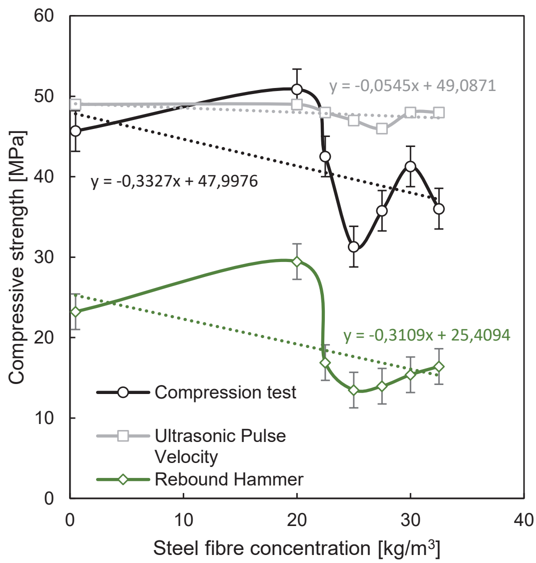

Fig. 9. Compressive strength results for three different methods

MPa smaller strength values than the destructive method. The highest compressive strength was achieved for the sample with a steel fibre concentration of 20 kg/m^3. Analysing Fig. 8, it can be seen that this sample had the highest density after twenty-eight days of curing. The same dependency between the density and the compressive strength can be seen for the other samples. The shape of the density curve is similar to the compressive strength curve. Thus, the final density of hardened concrete could have the largest impact on compressive strength.

3.2.3. Flexural tensile strength

From Fig. 10, it can be seen that steel fibres and their concentration doesn't have any effect on flexural tensile strength. Little anomaly of strength decreasing has been seen for sample with 25 kg/m^3 content of steel fibres. Because of the high air content in the fresh concrete mix and the lowest hardened concrete density for the sample with 25 kg/m^3 steel fibre concentration, it yields the lowest flexural tensile strength result.

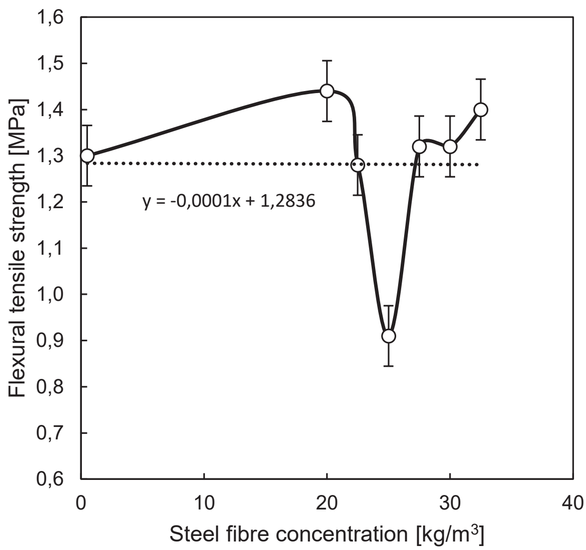

Fig. 10. Flexural tensile strength results

4. Discussion of the results

4.1. Effect of density and air content

The density decreases its value with increasing steel fibre concentration and, as a result, the air content in the concrete also increases. Small air bubbles have a negative impact on compressive and flexural tensile strength. Lower density (Fig. 11) indicates more air bubbles inside of the hardened concrete (Fig. 12) and it results in lower strength of the concrete samples.

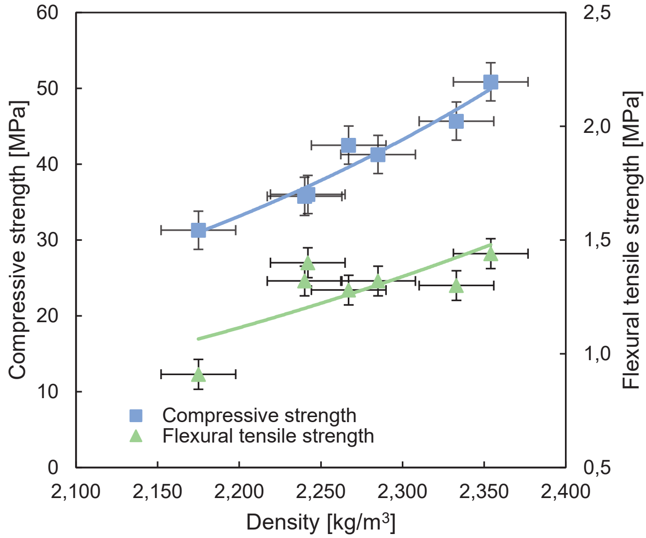

Fig. 11. Comparison of compressive (destructive method) and flexural tensile strength with density of hardened concrete

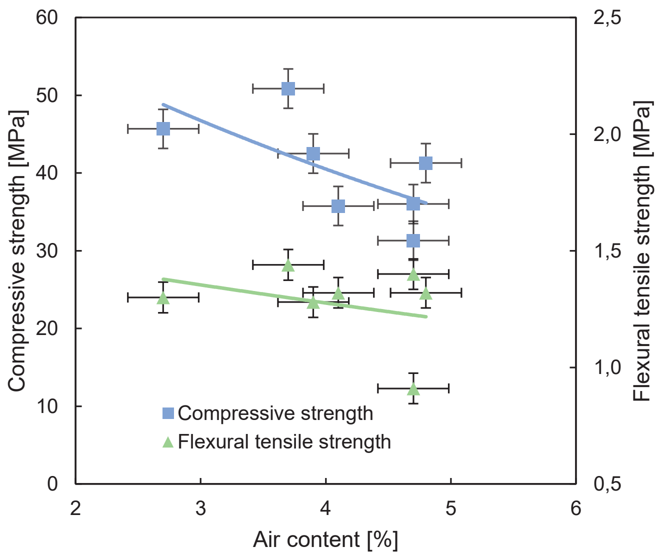

Fig. 12. Comparison of compressive (destructive method) and flexural tensile strength with air content in fresh concrete

4.2. Comparative analysis of the rebound hammer and ultrasonic pulse velocity results

In many pieces of research, non-destructive methods of the rebound hammer or/and ultrasonic pulse velocity have been analysed and compared [3; 8, p. 405; 19; 20]. However, the results of previous studies for these two methods are very similar and there aren't steel fibres inside the concrete samples. In this study, the results of compressive strength testing using each method are different. It shows that standard methods are not efficient enough to identify the compressive strength of concrete with steel fibres.

Analysing the compressive strength values (Fig. 9), it was observed that ultrasonic pulse velocity method yields similar results to the real compressive strength of the sample without steel fibres; however, it doesn't include steel fibres and their dosing. Rebound hammer method results are similar to the theoretical compressive strength 25 MPa. Moreover, this method includes the impact of steel fibres on compressive strength.

The researchers found the following relationship to calculate compressive strength using two non-destructive test results and the simplified formula:

$$f_c = f_{c,\,UPV} + \left(f_{c,RH} - f_{ck} \right) \tag{1}$$

Where f_c – estimated compressive strength of concrete; $f_{c,UPV}$ – ultrasonic pulse velocity compressive strength test result; $f_{c,RH}$ – rebound hammer compressive strength test result; f_{ck} – characteristic compressive cylinder strength of concrete at 28 days (concrete strength class).

From Fig. 13, it can be seen that by using formula (1) the real compressive strength can be estimated and calculated using results from the samples tested only by non-destructive methods (rebound hammer and ultrasonic pulse velocity). The problem of identifying the compressive strength of existing structures without their destruction can be resolved by results of this study. The calculated values are summarised with the tested values of compressive strength in Table 5.

Table 5. Summary of tested and calculated compressive strength values with errors

Tested compressive strength [MPa]	Calculated compressive strength [MPa]	Error [MPa]	Relative error *RE* [MPa]
45.68	47.21	1.53	1.03
50.86	53.45	2.59	1.05
42.51	39.88	2.63	0.94
31.30	35.48	4.18	1.13
35.76	34.95	0.81	0.98
41.28	38.37	2.91	0.93
36.02	39.40	3.38	1.09
Mean absolute error *MAE* [MPa]		2.58	

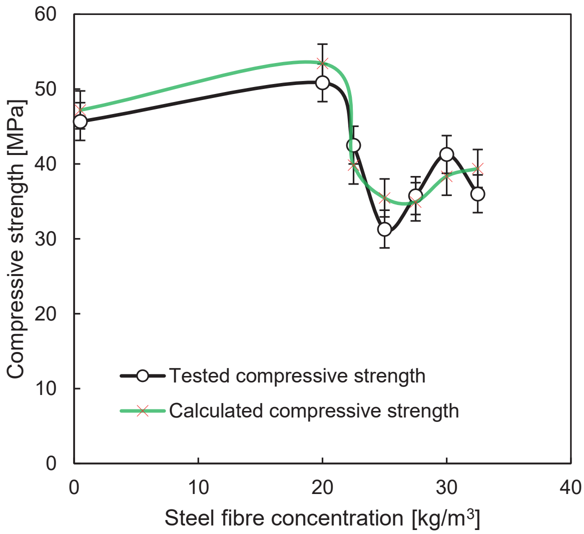

Fig. 13. Compressive strength estimation using non-destructive results

5. Conclusions

The purpose of this article was to evaluate the effect of different concentrations of steel fibres in the concrete matrix on concrete properties. In the research, properties of fresh and hardened concrete were analysed. Based on the performed tests, the following general conclusions can be drawn:

Higher steel fibre concentrations had an influence on fresh concrete workability. The slump height decreases with increasing concentrations of steel fibres. During the design of the concrete matrix, larger doses of superplasticiser should be considered.

The density results of fresh and hardened concrete shows that every matrix preparation can be executed differently. In the researcher's opinion, the tamping process using the concrete vibrator had the most influence on the density results. It should also be considered that some of the water could evaporate after removing the samples from the special container.

Higher air content in fresh concrete has a negative influence on the strength properties. With increasing concentrations of steel fibres, the air content value in fresh concrete also increases. During designing the concrete matrix, smaller steel fibre concentrations should be considered in order to obtain more favourable strength properties.

Higher steel fibre dosing (≥ 22.5 kg/m^3) decreases the compressive strength values.

The results of compressive strength are not clear for three different methods. This is because sufficient testing to compare the methods has not been performed.

For concrete reinforced with steel fibres, there is the possibility to estimate compressive strength using results from non-destructive test methods and formula (1), which was proposed by researchers.

Different concentrations of steel fibres has an impact on air content in fresh concrete and this has an impact on the density of hardened concrete. Better compressive and flexural tensile strength results are obtained for higher density of hardened concrete. Tested samples were tamped using a concrete vibrator for the same time for each mixture. Therefore, to obtain better strength results, it's important to pay attention to the time of tamping, which depends on the steel fibre concentration.

Analysing this research, it was found that there exists a correlation between ultrasonic pulse velocity and rebound hammer results. In further studies, the samples should be reinforced with polymer fibres and should be tested in a similar way to verify the effectiveness of formula (1) on other types of fibres.

References

[1] Johnston C.D., *Fiber-reinforced cements and concretes*, CRC Press, 2014.

[2] Balaguru P.N., Shah S.P., *Fiber-reinforced cement composites*, 1992.

[3] Agunwamba J.C., Adagba T., *A comparative analysis of the rebound hammer and ultrasonic pulse velocity in testing concrete*, Nigerian Journal of Technology 2012, 31(1), 31–39.

[4] Ongpeng J.M., Oreta A.W., Hirose S., *Characterization of Damage Using Ultrasonic Testing on Different Types of Concrete*, Materials Evaluation 2018, 76(11), 1532–1541.

[5] Zhao Q., Yu J., Geng G., Jiang J., Liu X., *Effect of fiber types on creep behavior of concrete*, Construction and Building Materials 2016, 105, 416–422.

[6] Kırgız M.S., *Fresh and hardened properties of green binder concrete containing marble powder and brick powder*, European Journal of Environmental and Civil Engineering 2016, 20(1), 64–101.

[7] Lee J.H., *Influence of concrete strength combined with fiber content in the residual flexural strengths of fiber reinforced concrete*, Composite Structures 2017, 168, 216–225.

[8] Ongpeng J., Oreta A., Hirose S., *Investigation on the sensitivity of ultrasonic test applied to reinforced concrete beams using neural network*, Applied Sciences 2018, 8(3).

[9] Wafa F.F., Ashour S.A., *Mechanical properties of high-strength fiber reinforced concrete*, Materials Journal 1992, 89(5), 449–455.

[10] Martí J.V., Yepes V., González-Vidosa F., *Memetic algorithm approach to designing precast-prestressed concrete road bridges with steel fiber reinforcement*, Journal of Structural Engineering 2014, 141(2), 04014114.

[11] Meda A., Plizzari G.A., *New design approach for steel fiber-reinforced concrete slabs-on-ground based on fracture mechanics*, Structural Journal 2004, 101(3), 298–303.

[12] Balaguru P., Foden A., *Properties of fiber reinforced structural lightweight concrete*, Structural Journal 1996, 93(1), 62–78.

[13] Sorelli L.G., Meda A., Plizzari G.A., *Steel fiber concrete slabs on ground: a structural matter*, ACI Structural Journal 2006, 103(4).

[14] Caratelli A., Meda A., Rinaldi Z., Romualdi P., *Structural behaviour of precast tunnel segments in fiber reinforced concrete*, Tunnelling and Underground Space Technology 2011, 26(2), 284–291.

[15] Kang S.T., Lee Y., Park Y.D., Kim J.K., *Tensile fracture properties of an Ultra High Performance Fiber Reinforced Concrete (UHPFRC) with steel fiber*, Composite Structures 2010, 92(1), 61–71.
[16] Ostrowski K., Sadowski Ł., Stefaniuk D., Wałach D., Gawenda T., Oleksik K., Usydus I., *The Effect of the Morphology of Coarse Aggregate on the Properties of Self-Compacting High-Performance Fibre-Reinforced Concrete*, Materials 2018, 11(8).
[17] Stawiski B., *The heterogeneity of mechanical properties of concrete in formed constructions horizontally*, Archives of Civil and Mechanical Engineering 2012, 12(1), 90–94.
[18] Ostrowski K., *The influence of CFRP sheets on the strength of short columns produced from normal strength concrete and fibre reinforced concrete*, Technical Transactions 2-B/2016, 145–156.
[19] Samarin A., Meynink P., *Use of combined ultrasonic and rebound hammer method for determining strength of concrete structural members*, Concrete International 1981, 3(03), 25–29.
[20] Abdulmajeed R., Hasan N., Amen D., *Comparative Analysis of the Rebound Hammer and Ultrasonic Pulse Velocity in Testing Concrete with Multi-Variation Equation*, International Review 2016, 7(6), 196–200.
[21] Di Prisco M., Felicetti R., Plizzari G.A. (eds.), *PRO 39: 6th International RILEM Symposium on Fibre-Reinforced Concretes (FRC)-BEFIB 2014*, vol. 1, RILEM Publications 2004.
[22] BS EN 206. (2016). BS EN 206:2016, *Concrete – Specification, performance, production and conformity* (includes Amendment :2016).
[23] Concrete C., Statements B. (2003). ASTM C 231:2003, *Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method*. American Society for Testing and Materials. M, 04.
[24] ASTM. (1997). C1018, *Standard Test Method for Flexural Toughness and First-Crack Strength of Fiber-Reinforced Concrete (Using Beam with Third-Point Loading)*. ASTM International, 04 (October), 7.
[25] ASTM. (2016), *Standard Test Method for Pulse Velocity Through Concrete*. ASTM C597-16. ASTM International.
[26] ASTM C805-02. (2002). 1. ASTM C 805, *Standard Test Method for Rebound Number of Hardened Concrete*. ASTM, 2–4.
[27] ASTM C143/143M. (2010). *Standard Test Method for Slump of Hydraulic-Cement Concrete*. ASTM C143, (1), 1–4.
[28] BS EN 12504-2. (2012). BS EN 12504-2:2012, *Testing concrete in structures – Part 2: Non-destructive testing – Determination of rebound number*.
[29] BS EN 12350-2. (2009). BS EN 12350-2:2009, *Testing fresh concrete. Part 2: Slump Test*.
[30] BS EN 12350-7. (2009). BS EN 12350-7:2009, *Testing fresh concrete. Part 7: Air Content – Pressure methods*.
[31] ASTM. (2002). ASTM C78/C78M – 02, *Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)*. ASTM International, 1–3.

If you want to quote this article, its proper bibliographic entry is as follow: Krzywiński K., Chajec A., *The effect of the concentration of steel fibres on the properties of industrial floors*, Technical Transactions, Vol. 4/2019, pp. 115–132.