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The Use of Dispersed Plastic Reinforcement in Concrete

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Abstract. The article deals with the issue of the usefulness of plastic reinforcement dispersed in concrete, including polypropylene fibers, and the impact of the amount of dosing of such fibers was assessed. The amount of addition was analyzed in the range of 0.5 to 2.0 kg/m^3. Fibrillated fibers arranged in bundles and crimped fibers were used in the tests. Fibers with a length of 50 mm were analyzed. The results were compared with test series with the addition of steel barbed fibers 50 mm long and 1.0 mm in diameter. The tests showed that steel fibers do not adversely affect the designed consistency of the concrete mix, unlike polypropylene fibers. The tests showed that, for strength and technological reasons, in the case of concrete reinforced with the addition of up to 20 kg/m^3 of steel fibers, polypropylene fibers in the amount of 1.5 kg/m^3 can be successfully used, with a decrease in bending and compressive strength not exceeding 10%.

Introduction

Continuous development of technology makes construction products meet the highest quality requirements. Taking care of the quality of the processes that are necessary to produce a construction product easily translates into the quality of the final product [1]. New technologies are introduced in every industry, including construction. In order for the investor to be able to evaluate new technological solutions, including new building materials, an analytical model should be developed that will enable the investor to assess the profitability and the degree of risk of introducing the solution or building material on the construction market. In this assessment, the key role is played by the final quality of the building material or the quality of building technology processes [2].

Continuous technological development also causes a systematic increase in the amount of waste in industry. This generates a problem with their disposal. Therefore, waste management is carried out in urban and rural areas to ensure environmental safety [3]. Some of the waste is used in the production processes of building materials. Recyclates currently used in the construction industry are fly ashes and slags from the combustion of fossil fuels added to concrete or cement mortars [4] and, for example, metallurgical waste used for the production of aggregates [5]. Concrete and mortar as composite materials with a cement matrix are commonly used in construction. Due to their composite characteristics, they are perfect for adding additives and admixtures to them, which can be recyclants. Research was carried out on such additives as: waste glass [6], PET waste [7], thermoplastic elastomers from the production of car mats [8] or fly ashes from biomass combustion [9], in all the mentioned studies, these additives in the form of recyclates did not deteriorate the properties of concretes and mortars.

The use of waste materials in the production of concrete does not guarantee an increase in the basic parameters of concrete, such as compressive strength, tensile strength in a bending test, which are crucial in terms of obtaining the appropriate quality of concrete in the context of its intended use, or consistency class and workability, which are crucial for from the point of view of the quality of the concrete placement technology at the destination. Additives in the form of fibers

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are used to improve the strength characteristics of concrete and to reduce its cracking. Most often, steel, polymer, glass and natural fibers are added [10]. According [11] steel fibers are straight or deformed fragments of cold-drawn steel wire, straight or deformed fragments of cut steel sheet, melt fibers, cut and rolled fibers from steel blocks, while polymer fibers according to [12] are straight or deformed fragments of extruded, oriented and cut polymeric material, used to make a homogeneous concrete mix. Polymer fibers are added to concrete in the form of short thin threads (up to 30 mm) of small diameter (0.02-0.05 +/- 0.05 mm) or rigid rods with a diameter of (0.2-0.5 +/- 0.5 mm) and lengths up to 60 mm. Polypropylene, polyethylene, polyester, nylon, polyacrylic or aramid are most often used to make polymer fibers [13]. In the case of steel fibers, the standard length is 10-60 mm. Fibers of this type usually have a round, flat or oval cross-section. The diameter of typical steel fibers is usually 0.2-1.5 mm. The most common shapes used for concrete are: straight, smooth, hooked, flattened at the ends and with split ends [14].

Methodology of Research

The aim of the work was to determine the effect of dosing fibers made of plastics (polypropylene) of different structure, the same length and the same material on the mechanical properties of the concrete mix and the finished concrete product. In addition, during the research work, the feature of the fresh concrete mix in the form of consistency class was determined. The results were compared with test series with the addition of hooked steel fibers and without the addition of fibers (control series).

Materials. The research used ingredients of natural origin, commonly used in construction, easily available. The concrete mix was designed using the successive approximation method (Kuczyński's method). Due to the burning of fiber additives, after reading the guidelines contained in [14–18] and based on preliminary tests, a limited W/C ratio of 0.4 was chosen. In order to obtain the required consistency class, the superplasticizer BASF MasterEase 5051 was used in the production of concrete mix in the amount of 2.5% of the cement mass. In addition, the following ingredients were used to produce the mix: Portland cement CEM V/A 32.5R, a mixture of gravel aggregate of the 2-8 mm and 8-16 mm fractions, sand of the 0-2 mm fraction and tap water from the intake in Częstochowa. The mix was designed in the S3 consistency class, and the aggregate mix was selected so that the graining curve was in the upper range of the field of graining boundary curves [14,15]. The design class of concrete is C30/37. Table 1 shows the concrete mix recipe.

Table 1. *Concrete mix recipe*

Type of ingredients	Amount of ingredients per 1 m^3 of the mix [kg]
Cement CEM V/A 32.5R	444
Water	178
Sand 0-2mm	934
Gravel 2 - 8 mm	536
Gravel 8 - 16 mm	646
Superplasticizer	11
W/C	0,40
Consistency class	S3

Table 2. *Properties of the polypropylene fibers used*

Properties	Unit	P1 fibers	P2 fibers
Type of polymer	-	polypropylene	polypropylene
Density	g/dm^3	0.91	0.91
Diameter	mm	1.5	1.0
Length	mm	50	50
Modulus of elasticity	kN/mm^2	2	2
Tensile strength	N/mm^2	600	600
Flash-point	°C	160	160
Melting temperature	°C	160	160

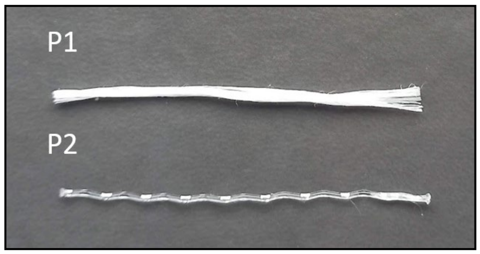

Fig. 1. *Polypropylene fibers used in the tests (P1 fiber at the top, P2 at the bottom) [own study].*

Two types of polypropylene fibers were used in the research. P1 in the form of a twisted bundle, fibrillated sections had a length of 50 mm (±1.5 mm), and a crimped fiber marked in the tests as P2 with a length of 50 mm (±1.5 mm). Fiber properties are presented in table 2.

In addition, non-galvanized steel reinforcement (fig. 2) in the form of a barbed wire was used for the tests. The fibers used in the tests were made of steel with a tensile strength of 1000-1020 MPa. They had a length of 50 mm and a diameter of 1.0 mm. The barbed fibers are designated S1. Table 3 shows the geometric parameters of the fibers and their properties.

Table 3. *Properties of the steel fibers used*

Properties	Unit	S1 fibers
Material	-	steel
Length	mm	50
Diameter	mm	1.0
Slenderness	L/d	50
Shape	-	hooked
Tensile strength	MPa	1000÷1020
Modulus of elasticity	GPa	210

Fig. 2. *Steel fibers used in the tests (S1 fiber) [own study].*

Methodology. The components of the concrete mix were measured by weight. The dosing of ingredients took place in exactly the same order in each test series. The concrete mix production procedure was consulted with the local concrete plant in order to reflect the industrial method of concrete production. First, 50% of the volume of aggregate with a fraction of 2-8 mm was dosed into the mixer, then pears with a fraction of 8-16 mm, and then 50% of the volume of sand was added. The ingredients were mixed for 1 minute. The superplasticizer was then mixed with water, and this mixture was added to the previously mixed aggregate mix. The ingredients were mixed for a period of 2 minutes. After this time, the remaining aggregate was added (50% of gravel of the 2-8 mm fraction and 50% of the gravel of the 8-16 fraction and 50% of sand), and then mixed for another 2 minutes. For the fiber-added batch, a pre-measured amount of fiber was added at this point. The mixing time of the test series with added fibers was 2 minutes for all series. The SK control lot contained no fibres. In total, 13 research series were performed. For each, the consistency was determined by the falling cone method in accordance with [19]. Each test series contained at least 6 samples (3 samples with dimensions of 150x150x150 mm and 3 samples with dimensions of 150x150x600). The amount of dosed fibers for individual test series is shown in Table 4.

Table 4. *List of research series*

Series name	**Type of added fibers**	**Number of fibers per 1 m^3 of the mixture [kg]**
SK	-	-
P1-S1	Polypropylene P1	0,5
P1-S2	Polypropylene P1	1,0
P1-S3	Polypropylene P1	1,5
P1-S4	Polypropylene P1	2,0
P2-S1	Polypropylene P2	0,5
P2-S2	Polypropylene P2	1,0
P2-S3	Polypropylene P2	1,5
P2-S4	Polypropylene P2	2,0
S1-S1	Steel S1	10
S1-S2	Steel S1	15
S1-S3	Steel S1	20
S1-S4	Steel S1	25

Standards in accordance with the requirements were used in the tests [20]. The mixture was placed in two equal layers and then vibrated for 25 seconds. The procedure for making test samples met the requirements contained in [21]. After 24 hours, the samples were removed from the molds and stored in water at 20±2°C until testing. After 28 days from the preparation of the samples, compressive strength tests were carried out according to [22] and tensile strength of concrete in a bending test - a simply supported beam loaded symmetrically with one force according to [23]. All tests were performed in a Toni Technik type 2030 testing machine in accordance with the requirements [24].

Research Results and Their Discussion

The results of consistency tests are presented in table 5

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Table 5. *Summary of consistency classes of tested concrete mixes*

Series name	Cone drop [mm]	Consistency class
SK	145	S3
P1-S1	120	S3
P1-S2	110	S3
P1-S3	70	S2
P1-S4	35	S1
P2-S1	140	S3
P2-S2	130	S3
P2-S3	110	S3
P2-S4	70	S2
S1-S1	140	S3
S1-S2	130	S3
S1-S3	115	S3
S1-S4	100	S3

The largest cone slump was obtained for a series of control concretes (SK). The consistency class here was consistent with the designed consistency. In the series with the addition of polypropylene fibers, a tendency to change the consistency class with the amount of added fibers was observed, while in the series with the addition of steel fibers this phenomenon was not observed.

Compressive strength tests were performed in accordance with the requirements of the standard [22] on a Toni Technik 2030 machine. The load increase was 0.5 MPa/sec. The averaged results along with the standard deviation are shown in Figure 3.

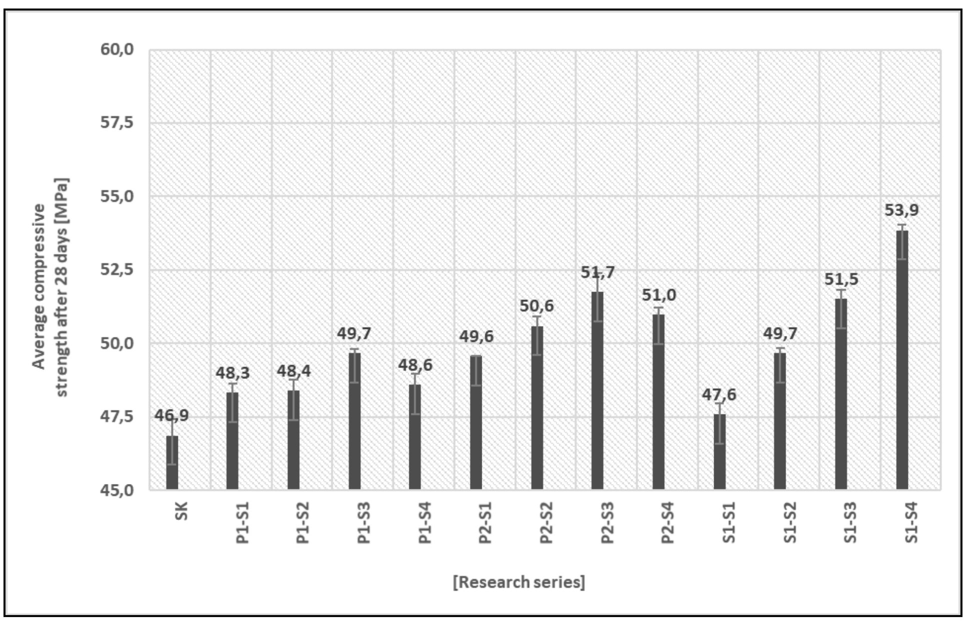

Fig. 3. *Compressive strength of tested concrete series.*

The average compressive strength of concrete was determined for all series after 28 days of curing of the samples. For the control series, fcm=50.80 MPa was obtained. Depending on the amount of polypropylene fibers P1 and P2 dosed, the value of the average compressive strength of concrete ranged from 48.3 MPa (P1-S1 series) to 51.7 MPa (P2-S3 series), while the standard deviation for all series was in the range of ± 0 .01MPa for the P2-S1 series to ±0.67MPa for the

P2-S3 series. For the series with the addition of steel reinforcement, the average compressive strength of concrete ranged from 47.6 MPa (series S1-S1) to 53.9 (series S1-S4), and the standard deviation was in the range of ± 0.18 MPa for S1-S4 series to ±0.37 MPa for S1-S1 series.

In the case of samples with steel reinforcement, the compressive strength increased with the amount of fibers added, while in the case of the series with the addition of polypropylene reinforcement, no such relationship was observed. The graph shows that the corrugated reinforcement (P2) had a better effect on the compressive strength of the concrete than the fibrillated reinforcement (P1). The addition of 2kg/m3 of this type of reinforcement caused a slight decrease in compressive strength. Tensile strength tests in the bending test were performed in accordance with the requirements of the standard [23] on a Toni Technik 2030 machine. The load increase was 0.5 MPa/sec. The averaged results along with the standard deviation are shown in Figure 4.

The average flexural strength of concrete was determined for all series after 28 days of curing of the samples. For the control series, f_{ct}=3.7 MPa was obtained. Depending on the amount of polypropylene fibers P1 and P2 dosed, the value of the average concrete flexural strength ranged from 3.8 MPa (P1-S1 series) to 4.7 MPa (P2-S3 series), while the standard deviation for all series ranged from ±0.04 MPa for P1-S4 series to ±0.14 MPa for P1-S3 series. For the series with the addition of steel reinforcement, the average concrete flexural strength ranged from 4.1 MPa (series S1-S1) to 5.0 (series S1-S4), and the standard deviation was in the range of ± 0.05 MPa for S1-S1 series to ±0.10 MPa for S1-S4 series.

In the case of samples with steel reinforcement, the bending strength increased with the amount of fibers added, while in the case of the series with the addition of polypropylene reinforcement, no such relationship was observed. The graph shows that the corrugated reinforcement (P2) had a better effect on the bending strength of the concrete than the fibrillated reinforcement (P1). The addition of 2kg/m^3 of this type of reinforcement caused a slight decrease in bending strength.

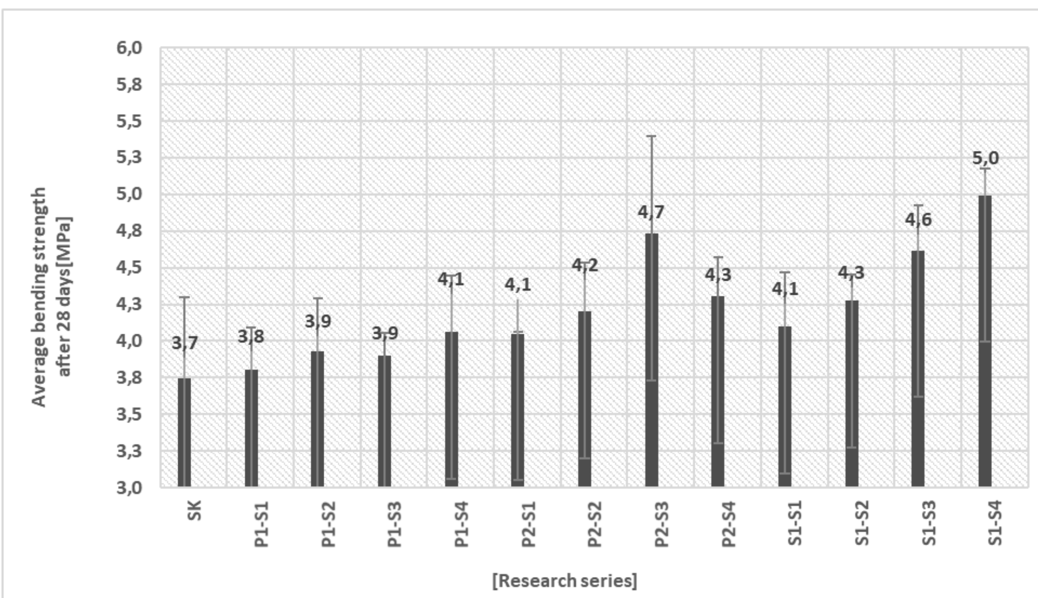

Fig.4. *Tensile strength of concrete in a bending test - simply supported beam symmetrically loaded with one force.*

Conclusions

In the case of compressive strength, the best series of concretes with the addition of polypropylene fibers was 4.5% lower than the best result of the series with the addition of steel fibers.

In the case of flexural strength, the best series of concretes with the addition of polypropylene fibers was 7% lower than the best result of the series with the addition of steel fibers.

Micromeshed polypropylene fibers do not significantly improve performance compared to crimped polypropylene fibers.

The addition of too much polypropylene fibers causes deterioration of the concrete mix structure and strength results. Tests have shown that the permissible value of the addition of polypropylene fibers is 1.5 kg/m^3.

On the basis of the tests carried out, it can be assumed that, for strength and technological reasons, in the case of concrete reinforced with the addition of up to 20 kg/m^3 of steel fibers, polypropylene fibers in the amount of 1.5 kg/m^3 can be successfully used, with a decrease in bending and compressive strength not exceeding 10 %.

The polypropylene reinforcement protruding above the surface is not dangerous for users and workers due to its rigidity, unlike the protruding steel reinforcement.

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