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Effect of dosing with propylene fibers on the mechanical properties of concretes

Paweł Helbrych[1] (*orcid id: 0000-0001-6907-0363*)
[1] Czestochowa University of Technology

Abstract: The article deals with the suitability of polypropylene fibers in concrete mixtures and the impact related to the amount of dosing of such fibers. The amount of addition in the range from 0.5 to 2.0 kg/m^3 was analyzed and the effects of dosing too little or too much fiber in concrete in terms of its mechanical strength were discussed. The test fibers were made of white polypropylene arranged in bundles 50 mm long. The samples were tested after 28 days of maturation, and the mechanical properties that were assessed included, the compressive strength and the tensile strength of the concrete in a bend test. The influence of the amount of fibers on the consistency of the concrete mixture was also investigated. The results were statistically analyzed and presented in the article.

Keywords: polypropylene fibers, dosing, cement matrix, fiber-reinforced concrete, concrete mechanical properties

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Introduction

The only correct way to develop industry today is to focus on reducing the consumption of exhaustible natural resources. Sustainable development means less exploitation of natural resources, resulting in less destruction of our planet. The World Commission on Environment and Development defines sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own requirements (Ayu et al., 2020). Therefore, currently used building materials are modified and improved to meet the ever-increasing needs of humanity without harming the environment

(Garbalińska et al., 2017; Halbiniak, 2012). It is common knowledge that concrete is resistant to compression, but weak to tensile strength. It has a low fracture toughness (Kakooei et al., 2012; Shahnawaz et al., 2017). Synthetic, steel, glass or natural fibers are added to concrete in order to reduce cracks and increase the tensile strength. Each type of fiber, depending on the material from which it is made, has its own properties that modify the concrete in a specific way. Synthetic fibers limit macrocracks and microcracks. (Glinicki, 2010; Zych, 2010). Currently, they are the most frequently used fiber for concrete after steel fibers. The most commonly used material is polypropylene (Mardani-Aghabaglou, 2019). Polypropylene yarns are most often used for concrete intended for industrial floors, road and airport pavements or prefabricated thin-walled elements (Pietrzak & Ulewicz, 2018). The aim of the study was to determine the optimal amount of polypropylene fiber dosing in concrete and to identify the effects of dosing too little or too much fiber in concrete in the context of concrete mechanical strength.

1. Research methodology and materials

Concrete was produced for testing, the components of which are widely used and easily available. The SK control mixture and 4 test series of concrete modified with the addition of polypropylene fibers with a length of 50 mm in various dosing amounts were designed. The concrete was designed using the analytical and experimental method, with the W/C ratio = 0.45. The ingredients used for the tested bars were: CEM II 32.5 R Portland cement, a mixture of 2-8 mm and 8-16 mm gravel aggregate, 0-2 mm fraction sand, BASF MasterEase 5051 superplasticizer in the amount of 2.5% of the cement mass. It was assumed that the class of concrete used for the tests should not be lower than C25 / 30, and the designed consistency was S3. All samples were made and tested in the Laboratory of the Faculty of Civil Engineering at the Czestochowa University of Technology. Table 1 presents the recipe of the concrete mix.

Table 1. Concrete mix recipe (*own research*)

Types of ingredients	Amount of ingredients per 1 m^3 of mixture, kg				
	SK	S1P	S2P	S3P	S4P
CEM I cement	372				
Water	168				
Sand 0-2 mm	770				
Gravel 2-8 mm	428				
Gravel 8-16 mm	550				
Superplasticizer	9.3				
Polypropylene fibers	0	0.5	1.0	1.5	2.0
W/C	0.45				
Consistency class	S3				

The fibers used for the tests were in the form of a bundle, white in color, 50 mm long (±1.5 mm). Depending on the test series, the fibers were dosed in the amount of 0.5 to 2.0 kg/m^3. The dosing of all components of the mixture was done by weight. The technique of dosing the fibers due to their quantity in relation to the control series was not changed. The fibers were dosed into the preformed concrete mix and then mixed again until the mixture was homogeneous. The times of mixing the concrete mix and the order of dosing of individual components for all series were the same. The concrete mix was laid in forms compliant with (PN-EN 12390-1:2013-03) in two layers. Each layer was compacted. The samples were formed in accordance with the guidelines contained in the (PN-EN 12390-1:2013-03) standard. The samples were disassembled after 24 hours, then, until the tests, they were stored at the temperature of 20±2°C and a relative air humidity of 100%. For all series of concrete, 3 cubic samples 150x150x150 mm, 12 samples 100x100 mm and 3 cuboidal samples 600x150x150 mm formed in accordance with (PN-EN 12390-1:2013-03) standard were made. After 28 days from making the samples, compressive strength tests according to (PN-EN 12390-2: 2019-07), and the tensile strength of the concrete in the bending test – free-supported beam symmetrically loaded with one force according to (PN-EN 12390-3:2019-07) were carried out. A frost resistance test was also carried out using the direct method (PN-EN 12390-5:2019-08) for the resistance class F100. All tests were performed on a Toni Technik type 2030 testing machine in accordance with the requirements of (PN-EN 206+A1:2016-12) at the Faculty of Civil Engineering of the Czestochowa University of Technology.

2. Research results

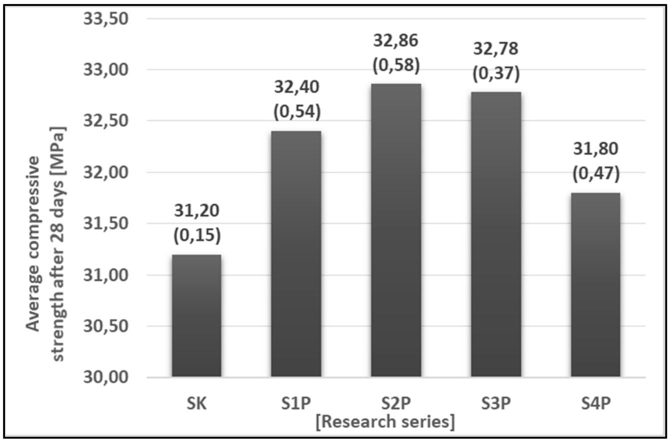
For each series, the consistency class was determined by the cone fall method according to (PN-EN 12350-2:2019-07). The results are presented in Table 2.

Table 2. Determination of the consistency class by the cone fall method according to (PN-EN 12350-2:2019-07) (*own research*)

Research series	Cone fallout mm	Consistency class
SK	135	S3
S1P	120	S3
S2P	105	S3
S3P	80	S2
S4P	40	S1/S2

The highest drop of the cone was recorded for the control series (SK), while the lowest for the S4P series with the highest content of polypropylene fibers (2 kg/m^3). As more polypropylene fibers were added, the consistency class changed from the initial S3 to the S1/S2 class.

The results of the compressive strength tests after 28 days of maturation are shown in Figure 1.



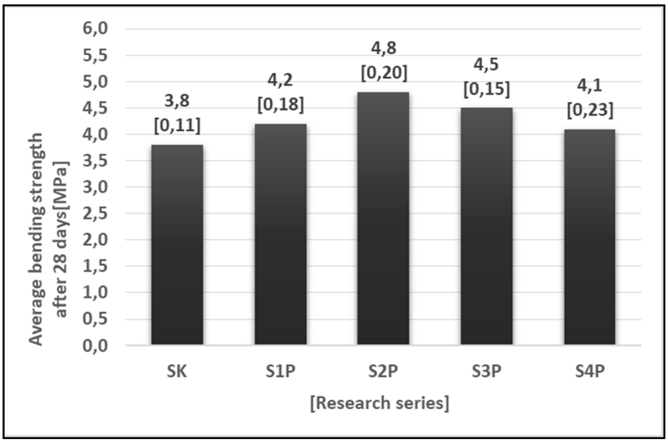
* the value in parentheses is the standard deviation

Fig. 1. Compressive strength results according to PN-EN 12390-3 of concretes of all series (*own research*)

The average compressive strength of the control concrete (SK), determined after 28 days, was f_{cm} = 31.20 MPa, for the series of concretes with the addition of polypropylene dispersed reinforcement with a length of 50 mm, it was: for the series with the addition of 0.5 kg/m^3 (S1P) – f_{cm} = 32.40 MPa, the series with addition of 1.0 kg/m^3 (S2P) – f_{cm} = 32.86 MPa, the series with addition of 1.5 kg/m^3 (S3P) – f_{cm} = 32.78 MPa, the series with addition of 2.0 kg/m^3 (S4P) – f_{cm} = 31.80 MPa.

The results of the concrete tensile tests in the bending test – a beam symmetrically loaded with one force according to PN-EN 12390-5 after 28 days of maturation are shown in Figure 2. The average tensile strength in the bending test of concrete (SK), determined after 28 days was f_{ct} = 3.8 MPa, for the series of concretes with the addition of polypropylene dispersed reinforcement with a length of 50 mm it was: for the series with the addition of 0.5 kg/m^3 (S1P) – f_{ct} = 4.2 MPa, the series with the addition of 1.0 kg/m^3 (S2P) – f_{ct} = 4.8 MPa, the additive series 1.5 kg/m^3 (S3P) – f_{ct} = 4.5 MPa, and the additive series 2.0 kg/m^3 (S4P) – f_{ct} = 4.1 MPa.

The result of the frost resistance tests using the direct method according to PN-88 / B06250 for the F100 resistance class is shown in Figure 3. The test result is positive when the average decrease in compressive strength does not exceed 20% for a given test series, and at the same time the average weight loss after the freezing and defrosting cycles does not exceeds 5%, in addition, none of the samples will be scratched or cracked. Each of the tested samples did not exceed a 20% decrease in compressive strength. The control series (SK) had the largest mean decrease, while the S2P series had the smallest. All lots with the addition of polypropylene fibers had a lower decrease in compressive strength after 100 cycles of freeze-thaw than the control series. Only in the case of the S4P series, cracks and scratches on the samples were noted. In all series, the weight loss did not exceed 5%.



*the value in parentheses is the standard deviation

Fig. 2. Concrete tensile strength results in a bending test – a freely supported beam symmetrically loaded with one force according to PN-EN 12390-5 (*own research*)

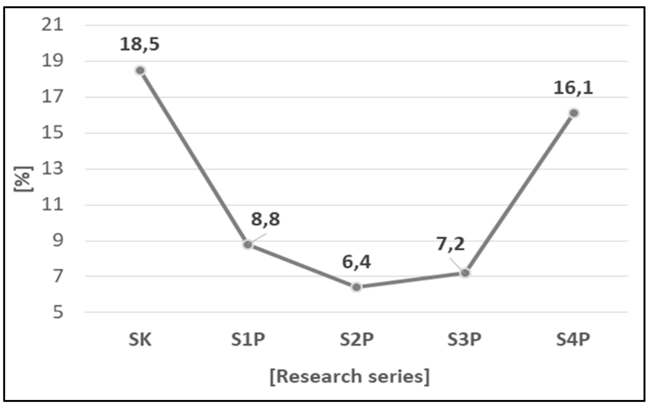


Fig. 3. A decrease in the average compressive strength of concretes in each series after the frost resistance test (*own research*)

Conclusions

The addition of fibers is important both for the properties of the fresh mix and for the concrete. Based on the observations, it can be concluded that the consistency and plasticity of the concrete mix changes with the increase in the amount of added fibrous additive. Adding too much polypropylene fibers with a length of 50 mm adversely affects the consistency and flatness of the concrete mix. In addition, too much polypropylene fibrous additives have a negative effect on the mechanical properties of concrete, such as compressive and bending strength or frost resistance. The research showed that the series with the addition of 2 kg/m^3 of polypropylene fibers obtained the worst results compared to other series with the addition of polypropylene fibers. After the tests, the optimal amount of added fibers can be considered to be 1.0 kg/m^3. The S2P series kept the designed consistency class and achieved the best results in compressive strength (5.05% better than the SK series), bending (20.83% better than the SK series) and frost resistance (65.41% better than the SK series). Interestingly, adding too little fiber gives better results than adding too much, and all series with polypropylene fiber added performed better than concrete from the control series.

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