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Original Scientific Paper

PROPERTIES OF STEEL-POLYPROPILENE HYBRID FIBERS REINFORCED CONCRETE

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Abstract. This paper present the results of mechanical properties of hybrid reinforced concrete made by adding polypropylene and steel fibers into concrete mixture. For the testing purposes were used steel fibers with hooked ends and monofilament polypropylene fibers. The total of 5 batches of concrete were made: concrete with addition of steel fibers, polypropylene fibers and their combination in amount of 0,5 % of the concrete volume. *The test results show that concretes made by adding of 0.4% steel and 0.1% polypropylene fibers have better performance compared to other concretes.*

Key words: *hybrid fibers, polypropylene fibers, steel fibers, concrete properties*

1. INTRODUCTION

In the recent years, a relatively new form building material: a hybrid reinforced concrete has been in the focus of attention. In general, the term "hybrid reinforced concrete" is used for materials whose cement matrix contains different types of micro reinforcement [1]. According to previous research, when concrete is loaded with the same external impact, hybrid reinforced concrete showed better cracking resistance than normal concrete [2]. By using the concept of hybridization, with two different fibers incorporated in a common cement matrix, the hybrid composite can offer more attractive engineering properties [3]. In general, addition of various combinations of fibers improve mechanical and dynamical properties of concrete [4]. Since now, different hybridization methods have been investigated in order to determine the influence of micro reinforcement shape, length, modulus and tensile strength of used fibers on concrete [5][6]. According to **Bentur** et al

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[7] improving mechanical and conductivity properties of concrete could be achieved by combining different types of polypropylene and steel fibers. The first type of fiber is more flexible and ductile, while the other is stronger and stiffer. So then, polypropylene fibers lead to improve toughness and strain capacity in the post-cracking zone, while steel fibers lead to improve first crack stress and ultimate strength. The influence of different fibers on the mechanical properties of high performance hybrid fibre concrete was investigated by **Qian et al.** [8]. Additions of a small fiber type had a significant influence on the compressive strength, but the splitting tensile strength was only slightly affected. In general, in the hardened loaded concrete, the polypropylene fibers with a small modulus of elasticity are inefficient for crack control, but then the inserted steel fibers with the high modulus of elasticity become prominent. Steel fibers act like micro-bridges in concrete, transferring stresses from one side of a crack onto the other. In this way reduce the concentration of stresses at the tops of cracks, which prevents their further development [9]. Presence of a considerable quantity of steel fibers in concrete reduces the workability of concrete which leads to the irregular consolidation of fresh concrete, which leads to the onset of micro-cavities and other deficiencies. By replacing the steel fibers with hybrid steel-propylene combination, the density of fresh concrete mix is reduced and its workability is increased while the polypropylene fibers partially negate the undesirable effects of steel fibers [10].

The main target of this research was to investigate benefits of using monofilament and steel fibers in the design on concrete mixtures. Mechanical characteristics of this way made hybrid reinforced concrete were compared to etalon concrete under the same test conditions.

2. Experimental procedure

2.1. Materials

In this study, Portland cement CEM I 52,5 R manufactured by CRH Popovac Serbia, was used for making concrete mixtures. Used cement fulfill all quality requirements recommended by SRPS EN 197-1 standard. The aggregate used in this research was a river aggregate originating from South Morava (Serbia). Three fractions of aggregate were used (0/4 mm, 4/8 mm and 8/16 mm) and all fractions fulfill the quality requirements prescribed by standards SRPS EN 206-1 and EN 12620. Particle size distribution of the individual fractions is presented in the Figure 1. Standard tap water was used for making all concrete mixtures and in order to reduce a water supply, as a reducer water additive SIKA Viscocrete 3070 was used.

In experimental research two types of fibers (polypropylene and steel) were used in order to product quality micro-reinforced concretes. Used polypropylene fibers belong to group of monofilament fibers producted by “Motvoz” Grosuplje (Slovenia). The type of this fibers was Fibrils S120 and belong to the group of circular cross sections and smooth surface fibers. The length of these fibers was 12 mm, while their average diameter was 0,037 mm. Used steel fibers belong to group of hook ended fibers produced by “Spajic” d.o.o. Company Negotin, Serbia. These steel fibers were made of steel marked C7D (number 1.0313) obtained by cold wire drawing. Type of used steel fibers was ZS/N 0.5×30 mm. The length of these steel fibers were 30 mm, while their average diameter was 0,50 mm. Used micro fibers were shown in the figure Figure 2.

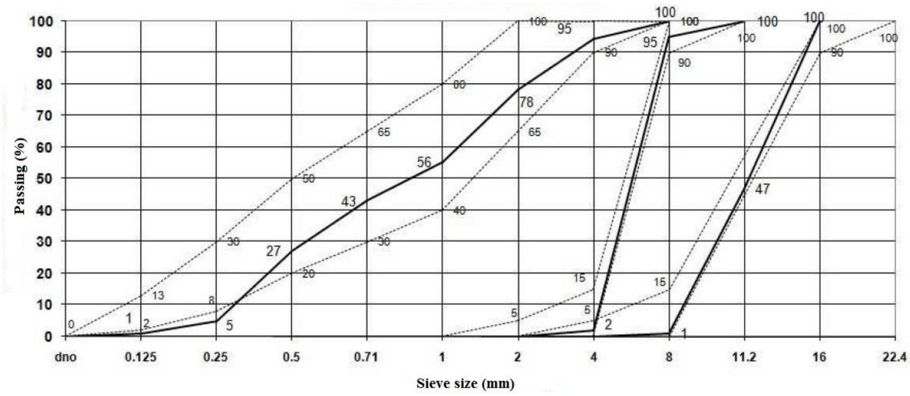

Fig. 1 Particle size distribution of used aggregate

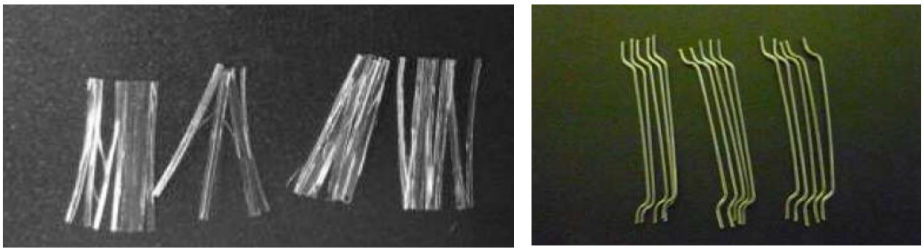

Fig. 2 Polypropylene (left) and steel (right) fibers used in experiment

2.2. Concrete mixture composition

For the purpose of determining the influence of different microfiber types and percentage on the performance of fresh and hardened concrete. Six batches of concrete were made. One batch of concrete was made only with steel hook addition in amount of 0,5 % of the volume. This batch is marked as “S5”. Other concrete batch was made with addition of polypropylene monofilament fibers in the amount of 0,5 % of the volume. This batch is marked as “P5”. The third batch of concrete was made by adding of 0,4% of steel and 0,1% of polypropylene fibers. According to using percentage of steel and polypropylene fibers in the concrete batch is names “S4P1”. According to the same analogy, other mixtures were named “S3P2” and “S2P3”. In order to compare the characteristics of micro reinforced concrete with ordinary cement concrete one more concrete batch was made. That batch was made without microfibers and it’s named as etalon “E”. Compositions of concrete mixtures for 1 m^3 of concrete are given in Table 3. The mixtures were made with the same water /cement ratio (m_w/ m_c = 0.45) and with the same aggregate /cement ratio (m_a/ m_c = 4.40). All mixtures were made with addition of the superplasticizer in the amount of 0,6% of the mass of cement.

Table 3 Composition of 1m^3 of concrete mixtures used in the experiment

Series of specimen	Aggregate			Cement	Water	Sika VSC 3070	Polyprop. fibers	Steel fibers
	0/4 mm	4/8 mm	8/16 mm					
	kg/m^3	kg/m^3	kg/m^3					
S5	782	435	522	396	178,2	2,38	-	39,25
P5	787	437	524	397	178,7	2,38	4,55	-
S4P1	783	435	522	395	177,8	2,37	0,91	31,40
S3P2	783	436	523	396	178,2	2,38	1,82	23,55
S2P3	784	436	523	396	178,2	2,38	2,73	15,70
E	792	440	528	400	180,0	2,40	-	-

2.3. Methods of examination

2.3.1. Methods of fresh concrete examination

Consistency of fresh concrete: In order to determine the consistency of fresh concrete, the method of setting by using Abrams cone was conducted. The testing was performed (Figure 3 - left) according to standard SRPS EN 12350-2:2010.

Fresh concrete density test: Testing of fresh concrete density (Figure 3 middle) was performed according to standard SRPS EN 12350-6:2010. This test was conducted by using a vessel of 8000 cm^3 volume, and concrete was vibrated.

Air content test: This test was performed in order to determine the percentage of air drawn into the fresh structure of concrete (Figure 3 - right). The test was conducted according to standard SRPS EN 12350-7:2010. In this case the porosimeter of vessel density was used.

Fig. 3 Testing the fresh concrete properties: Slump test (left), Density test (middle), Air content test (right)

2.3.2. Methods of hardened concrete examination

Bulk density of hardened concrete: Test of the density of concrete was performed by using the specimen cubes having side of 150 mm. The testing was performed according to standard SRPS EN 12390-7.

Compressive and flexural strength test: Determination of compressive strength was performed according to the SRPS EN 12390-3 standard. The samples of concrete cubes, having dimensions 150 x150 x 150 mm at the age of 2, 7 and 28 days. Testing was performed on a hydraulic press UTC-5740 manufacture by UTEST. Flexural strength of concrete prisms having dimension 100 x 100 x 400 mm was tested according to standard SRPS EN 12390-5 at the age of 28 days. The test was performed on the hydraulic press UTCM-6710 manufacture by UTEST.

Tensile splitting strength test: Determination of tensile splitting strength test was performed on cylindrical cores Ø150×300 mm according to standard SRPS EN 12390- 6 at the age of 28 dana. The test was performed on the hydraulic press UTC-5740 manufacture by UTEST.

Pull-off test: In order to determine adhesion of different materials to the concrete base the bond strength test was conducted. The test was performed according to SRPS EN 1542:2010 standard. Prismatic concrete samples having dimensions 200 x 200 x 50 mm were tested at the age of 28 days. According to standard, the preparation of samples was done by incision of Ø50 mm ring in the depth of 15 ± 5 mm. After cutting, steel seals of 50 mm and 20 mm high were gluing to the concrete surface by using epoxy glue, (Sikadur-31 CF Normal). Testing of the concrete samples was performed after two days by using „Pull-off“ apparatus manufactured by Matest (Dyna Z-16) of the capacity up to 16 kN.

Drop-weight test: Drop-weight test resistance was performed according to the recommendations of **Ukrainczyk** [11]. Concrete slab having dimensions 400 × 400 × 60 mm at the age of 28 days were fixed inside a steel frame and loaded by drop-weight of the 3kg mass from the height of 30 cm. The criterion for evaluation of the testing results is related to the number of weight impacts until the onset of the first crack (N1), as well as to the number of weight impacts until the failure of the slab (N2). For this purpose, the failure comprises either the complete propagation of a crack across the full height of the sample or a total failure (actual breaking) of the sample. The tests were performed on three specimens of each batch. Each specimen was tested to the maximum number of 40 impacts, unless the failure occurred prior to that. On the basis of the number of registered weight impacts was calculated the magnitude of energy expanded for the onset of the first cracks on the sample (E1), i.e. the total energy corresponding with the failure of the material (E2) according to the formula:

$$E_N = N \cdot E = N \cdot m \cdot g \cdot h \; [J] \qquad (1)$$

where: E – energy consumed , corresponding to one weight impact,
E_N – total energy after N weight impacts,
m - weight mass – impact mass (m=3,0 kg),
g – Gravitational acceleration (g=9,81m/s^2),
h – Initial height of the weight (h=0,30 m).

4. Results and Discussion

4.1. Fresh concrete properties

The results of fresh concrete properties are presented in Table 4.

Table 4 Characteristic of fresh concrete properties

Series of specimen	Slump [mm]	Air content [%]	Density [kg/m^3]
E	110	3,0	2342
S5	100	3,6	2356
P5	30	4,8	2330
S4P1	90	3,7	2348
S3P2	75	3,9	2344
S2P3	55	4,2	2338

Consistency of concrete: On the basis of the test results, the highest slump was measured for the etalon mixture marked as “E” is 110 mm, while the concrete mixture “P5” had lowest slump value is 30 mm. Slump of concrete named “S5” was smaller than on etalon “E”. The difference between the slumps of this two measurement was 10 mm. The slump value of hybrid fiber reinforced mixtures is ranged in between the values of the mixtures “S5” and “P5”. As the number of polypropylene fibers, in a volume unit, is higher than the steel ones, it could be concluded that the compactness of concrete depends on the number, type and characteristics of used fibers.

Concrete density: The highest density was measured on the batch named “S5” and is 2356 kg/m^3. The smallest density was measured on the batch named “P5” and is 2330 kg/m^3. The density of hybrid fiber reinforced mixtures ranges between these two values. Also, as the value of the density of fresh concrete mix is influenced by the density of polypropylene (910 kg/m^3) and steel fibers (7850 kg/m^3) and it’s clear that density of concrete is in accordance of used fibers type.

Air content: According to the air content test results, the addition of polypropylene and steel fibers is in correlation with fresh concrete air content. By comparing the obtained results, it can be seen that the mixtures reinforced by the polypropylene fibers only have higher air content in comparison to the mixtures made with steel fibers only. This is logical regarding that the number of polypropylene fibers in a unit of volume is considerably higher in respect to the steel fibers. As expected, increase of polypropylene fibers in hybrid fiber reinforced mixtures increase the content of entrained air in fresh concrete.

4.2. Hardened concrete properties

The results of compressive strength, flexural strength, splitting tensile strength and bond strength by using “Pull-off” test properties are presented in Table 5, while the results of Drop-weight test are presented in Table 6.

Table 5 Characteristic of hardened concrete properties

Series of specimen	Density [kg/m^3]	Compressive strength [MPa]			Flexural strength [MPa]	Splitting tensile strength [MPa]	Bond strength by Pull-off [MPa]
		2 days	7 days	28 days			
E	2338	39,22	50,67	58,22	5,69	4,34	4,71
S5	2350	40,90	48,14	61,52	6,70	5,11	5,26
P5	2328	43,41	50,00	59,89	6,46	4,94	5,42
S4P1	2342	41,22	48,86	62,18	6,95	5,24	5,56
S3P2	2341	42,01	47,53	60,75	6,55	5,06	5,34
S2P3	2333	42,32	49,44	59,33	6,35	4,85	5,20

Compressive strength: Considering the types of concrete mixes which were analyzed in this research, the value of compressive strength and its increase in time was affected by the type and geometry of used fibers, as well as the ratio of steel and polypropylene fibers in the mixture. According to the results, the usage of fiber reinforced confirms the known fact that the addition of fibers, primarily the polypropylene ones, does not have a notable contribution in terms of increase of compressive strength of concrete. Namely, it is possible to considerably increase compressive strength of the concrete reinforced with steel fibers, but only in the case of a higher dosage of fibers (added steel fibers exceeding 0,5 % in volume). Since in this research, the steel fibers were added to the maximum amount of 39,25 kg/m3, i.e. 0,5 % of volume, it was logical to expect a small increase of compressive strength, in comparison with the reference concrete. In terms of concretes reinforced with polypropylene fibers, the increase of compressive strength is less prominent, which is explained mostly by the excess of entrained air during mixing and placement of concrete. By analyzing the results of compressive strength of 2 days old samples, it can be observed that there is a considerable contribution of fibers, primarily propylene ones, to the increase of strengths, which is logical because in that period of hardening the cement rock is the main factor of concrete strength. In the 7 days old samples, there is a decrease in compressive strength of fiber reinforced concretes in comparison with the reference concrete, while at the age of 28 days, fiber reinforced concretes have slightly higher compressive strengths in comparison with the reference concrete. At the age of 28 days, the highest value of compressive strength was recorded for the mixture marked as “S4P1” which is for 6,8 % more in comparison with the reference concrete. The increase of compressive strength of the mixture marked “S5” amounts to 5,7 %, of the mixture marked “S3P2” it amounts to 4,3%, of the mixture marked “P5” it amounts to 2,9 % and of the mixture marked “S2P3” it amounts to 1,9% in comparison with the reference concrete.

Tensile strength: The addition of fibers to the concrete primarily provide higher tensile strength of concrete. In a similar way as in case of the compressive strength, the flexural strength is influenced by type and geometry of applied fibers, as well as ratio of steel and polypropylene fibers in concrete. The mixture marked “S4P1” had the highest value of flexural strength which was for 22,1 % higher than the reference concrete. The increase of the flexural strength of the mixture marked “S5” was 17,8%, of the mixture “S3P2” it was 15,1 %, of the mixture “P5” it was 13,5% and of the mixture “S2P3” it was 11,6 % in comparison with the reference concrete.

Splitting tensile strength: According to the test results of the splitting tensile strength it can be concluded that fiber reinforcing, regardless of the type of fiber, contributed to improvement of this mechanical characteristic of concrete. The highest value of splitting tensile strength was achieved by the mixture marked “S4P1” which is for 20,7 % higher than the reference concrete. The increase of splitting tensile strength of the mixture marked “S5” is 17,7 %, of the mixture marked “S3P2” it is 16,6 %, of the mixture marked “P5” it is 13,8 % and of the mixture marked “S2P3” 11,8 % in comparison with the reference concrete.

„Pull-off“ test: The highest value of bond strength by „Pull-off“ test was achieved by the mixture marked “S4P1” which is for 18,0 % higher in respect to the reference concrete. The increase of bond strength of the mixture marked “S5” is 15,1 %, of the mixture marked “S3P2” it is 13,4 %, the mixture marked “P5” it is 11,7 % and the mixture marked “S2P3” it is 10,4 % in comparison with the reference concrete. It should be emphasized that the value of bond strength by „Pull-off“ test was to great extent affected by the arrangement of reinforced fibers within the concrete composite. Namely, since the polypropylene fibers are smaller and more numerous in comparison with the steel ones, the distribution of these fibers within the concrete composite is more homogenous in terms of quantity and direction. It is particularly important for the surface parts of the concrete sample (in practice, it is a structural concrete element) on which the value of bond strength by „Pull-off“ test is tested. It is logical that higher bond strengths by „Pull-off“ tests will be obtained, if a larger number of fibers in the surface zone of concrete are oriented in the direction or at a small angle to the direction of pull-off force action.

Table 6 Drop-weight test results

Series of specimen	The energy consumed for the onset of the first crack [J]	The energy consumed for the failure [J]
E	61,8	88,3
S5	132,4	> 353,20 (927,0)
P5	88,3	238,4
S4P1	158,9	> 353,20 (697,5)
S3P2	132,4	> 353,20 (547,4)
S2P3	105,9	> 353,20 (441,5)

Drop-weight test: Steel and propylene fibers contributed to the increase of the impact resistance of concrete, both in terms of an increase of the absorbed energy until the onset of initial damage (first cracks) and in terms of retaining serviceability during a protracted exposure to impact loads after the onset of the first cracks. Micro-reinforcing using only steel fibers, as well as hybrid micro-reinforcing contributed more to the enhancement of the impact resistance of concrete than the micro-reinforcing using only polypropylene fibers. The hybrid micro-reinforcing where a combination of steel and polypropylene fibers in the 4:1 ratio was implemented, caused the highest demand of the energy required to cause the onset of the first cracks, in comparison to other concretes. However, the highest demand of energy required for the impact load failure of a slab was used for concrete which was micro-reinforced with steel fibers only.

5. CONCLUSION

In the present paper, a study of the effect of different fibers on physical-mechanical properties of hybrid reinforced concrete was carried out. Concrete mixtures were designed by using Portland cement and polypropylene and steel microfibers in the amount of up to 0,5 % of the volume in order to improve hybrid concrete properties.

The results can be summarized as follows:

- The workability of the fresh fibers in concrete mixtures depends upon the proportions of the micro-fibers. Also, increase of polypropylene fibers in hybrid fiber reinforced mixtures increase the content of entrained air in fresh concrete, but also reduce slump and fresh concrete density.
- The hybrid micro-reinforcement contributed to enhancement of mechanical characteristics of concrete in comparison to the reference concrete.
- Micro-reinforced concretes are more resistant to impact load in comparison to the non-reinforced concretes, irrespective of the type of added fibers.
- The hybrid micro-reinforcing where a combination of steel and polypropylene fibers in the 4:1 ratio was implemented, caused the highest demand of the energy required to cause the onset of the first cracks, in comparison to other concretes. However, the highest demand of energy required for the impact load failure of a slab was used for concrete which was micro-reinforced with steel fibers only.

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MIKROARMIRANI HIBRIDNI BETONI ARMIRANIH ČELIČNIM I POLIPROPILENSKIM VLAKNIMA

U ovom radu predstavljeni su rezultati ispitivanja mehnaičkih karakterisitka hibridnih betona armiranih mikrovlaknima vlaknima. Ispitivanje je sprovedeno na mešavinama betona spravljenim sa čeličnim vlaknima zakrivljenih krajeva i monofilamentnim polipropilenskim vlaknima. U svrhu ispitivanja napravljeno je ukupno pet betonskih serija Jedna betonska serija spravljena je samo sa čeličnim vlaknima kao dodatkom, dok su preostale četiri serije betona spravljene sa kombinacijom čeličnih i polipropilenskim vlaknima u iznosu od 0,5 % zapremine. Prema rezultatima ispitivanja može se zaključiti da betoni spravljeni sa dodatkom 0,4% čeličnih i 0,1% polipropilenskih vlakana imaju bolje mehaničke karakteristike u odnosu na ostale mikroarmirane betona spravljene pri drugim procentualno-zapremninskim odnosima mikrovlakana.

Ključne reči: *hibridna vlakna, polipropilenska vlakna, čelična vlakna, karakteristike betona*