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IMPACT RESISTANCE OF HYBRID-REINFORCED CONCRETE

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ABSTRACT

In order to prevent the onset and propagation of cracks, as well as to increase toughness and other mechanical characteristics of concrete, the concrete is micro-reinforced using fibers of a variety of materials. Micro-reinforcing of concrete can be performed using one type of fibers or with a combination of different types of fibers (hybrid micro-reinforcing). The paper presents the research of properties in the fresh and hardened state, as well as impact resistance of hybrid fiber reinforced concretes with steel and polypropylene fibers. The impact resistance of concrete represents the quantity of absorbed energy which characterizes its ability to resist failure due to dynamic loads. For the testing purposes were used steel fibers with hooked ends and monofilament polypropylene fibers, and a total of 5 batches of concrete were made: concrete with addition of steel fibers, in the amount of 0,5% of the volume (S5), concrete with addition of polypropylene fibers in the amount of 0,5% of the volume (P5), concrete with addition of 0,4% of steel and 0,1% of polypropylene fibers (S4P1), concrete with addition of 0,3% of steel and 0,2% of polypropylene fibers (S3P2) and concrete with addition of 0,2% of steel and 0,3% of polypropylene fibers (S2P3). The testing results demonstrated that the concretes with the addition of 0,4% of steel fibers and 0,1% of polypropylene fibers (S4P1) have better impact resistance in comparison to other concretes.

Keywords: concrete, hybrid fiber-reinforced, steel fiber, polypropilene fiber, impact resistance.

SAŽETAK

U cilju sprečavanja pojave i propagacije prslina, kao i povećanja žilavosti i drugih mehaničkih karakteristika betona vrši se ojačanje u vidu mikroarmiranja vlaknima od različitih materijala. Mikroarmiranje betona može se izvršiti jednom vrstom vlakana ili kombinacijom različitih vrsta vlakana (hibridno mikroarmiranje). U radu je prikazano istraživanje performansi u svežem i očvrslom stanju, kao i udarne otpornosti hibridno mikroarmiranih betona sa čeličnim i polipropilenskim vlaknima. Udarna otpornost betona predstavlja količinu apsorbovane energije kojom se karakteriše njegova sposobnost da se odupre lomu usled delovanja dinamičkog opterećenja. Za potrebe istraživanja korišćena su čelična vlakna sa ojačanim krajevima i monofilamentna polipropilenska vlakna, a napravljeno je ukupno 6 serija betona: etalon beton (E), beton sa dodatkom samo čeličnih vlakana u iznosu od 0,5% prema zapremini (S5), beton sa dodatkom samo polipropilenskih vlakana u iznosu od 0,5% prema zapremini (P5), beton sa dodatkom 0,4% čeličnih i 0,1% polipropilenskih vlakana (S4P1), beton sa dodatkom 0,3% čeličnih i 0,2% polipropilenskih vlakana (S3P2) i beton sa dodatkom 0,2% čeličnih i 0,3% polipropilenskih vlakana (S2P3). Rezultati ispitivanja pokazuju da betoni sa dodatkom 0,4% čeličnih i 0,1% polipropilenskih vlakana (S4P1) imaju bolje mehaničke karakteristike i udarnu otpornost u odnosu na ostale betone.

Ključne riječi: beton, hibridno mikroarmiranje, čelična vlakna, polipropilenska vlakna, udarna otpornost.

INTRODUCTION

Hybrid fiber reinforced concretes represent a relatively new building material which consists of concrete with fine fractions of aggregate and fibers of various materials representing reinforcement of the concrete. In order to make this concrete usable in engineering structures, it is necessary to predict its mechanical characteristics, strength and durability so that the failure risk of these structures could be assessed. In the numerous research [1-3] different types of reinforcement fibers were used (straight and curved steel fibers, carbon, polymer fibers etc) which can generally be divided into metallic and non-metallic fibers. Addition of various combinations of these fibers to concrete and their impact on mechanical and dynamical properties was examined [4].

Crack control plays a crucial role in the performance life of concrete construction. This is because the settlement and shrinkage cracks may pass through fresh concrete, thus forming planes of weakness and lowering the integrity of the concrete constructions. Further, the service loads may overstress hardened concrete for cracking, leading from cracking to substantial failure in concrete. Concerning the crack control, the incorporating of discrete fibers into the vulnerable concrete is useful and effective. The resulting fiber-reinforced concrete exhibits satisfactory resistance to crack formation and propagation. Because no single type of fibers can universally build into the concrete the resistance, the hybrid fiber system emerged as another resistance builder. It has been shown [5] that 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 because the presence of one fiber enables the more efficient utilization of the potential properties of the other fiber. Most often those are combinations of metallic and non-metallic fibers, and in this experiment, combination of steel and polypropylene fibers was used, which according to the research conducted by Sivakumur [1] provides the best characteristics to concrete, in comparison with the combinations of steel fibers with glass or polyester fibers.

There are several test methods that evaluate the impact strength of fiber reinforced concrete where the simplest method is the drop-weight test proposed by the ACI committee 544. Experimental results from concrete specimens containing 0.1% - 2% polypropylene fibers showed that the impact strength of concrete increased both for the first crack and final fracture compared with plain concrete [7]. Marar et al. [6] showed that for FRCs containing 0.5%, 1%, 1.5% and 2% hooked-end steel fibers with aspect ratios of 60, 75 and 83, the samples with a higher fiber content (in all of aspect ratios) had a higher impact strength; also for specimens with 2% fiber content and aspect ratios equal of 60, 75 and 83, the absorbed energies increased by 38, 55 and 74 times, respectively. Using a drop hammer apparatus, Nataraja et al. [8] investigated the impact strength of steel fiber-reinforced concrete with an aspect ratio of 40 and two strength types, 30 MPa and 50 MPa. The results showed that the impact strength of all of the samples for the first crack and final fracture increased as the volume fraction of fibers increased. Song et al. [9] studied the impact resistance of (HSC) and high strength fiber-reinforced concrete (HSFRC) with a 1% volume fraction of hooked-end steel fibers with length of 3.5 mm and aspect ratio of 48. The results showed a 10% and 3% increase in impact resistance of HSFRC and HSC, respectively. Bindiganavile et al. [10] investigated the effect of the loading rate on the performance of FRC. They showed that for higher rates of loading, the impact resistance of the concrete with polypropylene fibers was higher than with steel fibers. In several investigations it was indicated that usage of fibers, especially steel fiber, improves impact resistance of concrete [11-12].

EXPERIMENTAL RESEARCH

The reference concrete was produced with the Portland cement CEM I 52.5 R. For preparation of concrete, the aggregate obtained by mixing three fractions 0/4, 4/8 and 8/16 mm from the river aggregate of the Southern Morava River was used. Two types of fibers were used for production of micro-reinforced concretes: polypropylene fibers FIBRILs S120 produced by “Motvoz” Grosuplje from Slovenia and steel fibers ZS/N 0.5x30 mm produced by “Spajic” d.o.o. Company Negotin from Serbia. The steel ZS/N 0.5x30 mm belong to the group of hook ended fibers, while the polypropylene fibers of FIBRILs S120 type belong to the group of monofilament fibers of circular cross sections and smooth surface. The fibers characteristics are given in the Table 1. Also used was water reducer SIKA Viscocrete 3070.

	Polypropylene fibers	Steel fibers
Characteristic	FIBRILs S120 (monofilament fibers)	ZS/N 0.5x30 mm (hook ended fibers)
Fiber length	12 mm	30 mm
Diameter (equivalent)	0.037 mm	0.50 mm
Aspect ratio	324	60
Tensile strength	300,7±31,7 N/mm^2	1100±165 N/mm^2

Table 1. Characteristics of polypropylene and steel fibers

Six mixtures for testing fresh and hardened concrete properties were made. The reference mixture was made by the river aggregate, cement, water and water reducer, marked with E. The mixture marked S5 was made with addition of steel hook ended fibers ZS/N 0.5x30 mm, in the amount of 0,5% of the volume; P5 with addition of 0,5% polypropylene monofilament fibers FIBRILs S120, in the amount of 0,5% of the volume; S4P1 with addition of 0,4% of steel and 0,1% of polypropylene fibers; S3P2 with addition of 0,3% of steel and 0,2% of polypropylene fibers and S2P3 with addition of 0,2% of steel and 0,3% of polypropylene fibers. The compositions of the concrete mixtures are given in the Table 2.

The impact resistance of concrete was tested by the so called. „Drop-weight test" according to the recommendations of professor Ukrainczyk [13] / adapted to the requirements of fiber reinforced concretes. A similar test was performed in the paper [14]. The test setup is displayed in figure 1, and the procedure is as follows: a constant mass 3kg weight is dropped on the sample from the constant height of 30 cm. The test specimen is a concrete slab having dimensions 40×40×6 cm fixed inside a steel frame, anchored to the floor. After each weight impact, a visual macroscopic examination of concrete surface is conducted, for the purpose of detection of potential damage on the sample. In this case, the damage is considered a clearly visible crack, occurring on the lower surface of the concrete sample.

Series of specimen	**Aggregate**			**Cement**	**Water**	**Sika VSC 3070**	**Polypropylene fibers Fibrils S 120**	**Steel fibers ZS/N 0.5x30**
	0/4 mm	**4/8 mm**	**8/16 mm**					
	kg/m^3	**kg/m^3**	**kg/m^3**					
E	792	440	528	400	180, 0	2,40	-	-
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,	2,38	1,82	23,55
					2			
S2P3	784	436	523	396	178, 2	2,38	2,73	15,70

Table 2. Composition of 1m3 of concrete mixtures used in the experiment

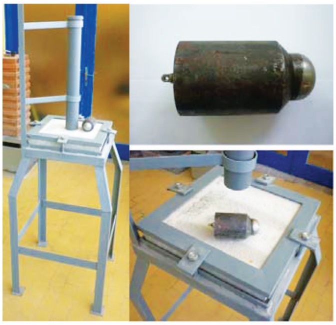

Figure 1. Test setup of concrete impact resistance testing by the „Drop-weight“ method

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).

RESULTS OF EXPERIMENTAL RESEARCH

The tests results of fresh and hardened concrete are presented in the tables 3 and 4.

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

Table 3. Characteristics of concrete in fresh state

Series of specimen	Density [kg/m^3]	Compressive strength [MPa]			Flexural strength [MPa]	The energy consumed for the onset of the first crack [J]	The energy consumed for the failure [J]
		2 days	7 days	28 days			
E	2338	39,22	50,67	58,22	5,69	61,8	88,3
S5	2350	40,90	48,14	61,52	6,70	132,4	> 353,20 (927,0)
P5	2328	43,4	50,00	59,89	6,46	88,3	238,4

		1					
S4P1	2342	41,2 2	48,86	62,18	6,95	158,9	> 353,20 (697,5)
S3P2	2341	42,0 1	47,53	60,75	6,55	132,4	> 353,20 (547,4)
S2P3	2333	42,3 2	49,44	59,33	6,35	105,9	> 353,20 (441,5)

Table 4: Characteristics of concrete in hardened state

DISCUSSION OF RESULTS AND CONCLUSION

On the basis of the test results provided in the Table 3, it can be concluded that the hybrid micro-reinforcement contributed to enhancement of mechanical characteristics of concrete in comparison to the reference concrete. It can also be concluded that micro-reinforced concretes are more resistant to impact load in comparison to the non-reinforced concretes, irrespective of the type of added fibers. 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.

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