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Novi Sad

UNIVERSITY OF NOVI SAD
FACULTY OF TECHNICAL SCIENCES
DEPARTMENT OF CIVIL ENGINEERING
AND GEODESY
DEPARTMENT OF ARCHITECTURE AND URBAN
PLANNING
IN COOPERATION WITH
ASSOCIATION OF STRUCTURAL ENGINEERS OF
SERBIA

13 iNDiS 2015

PLANNING, DESIGN, CONSTRUCTION AND RENEWAL IN THE CIVIL ENGINEERING

International Scientific Conference

PROCEEDINGS

Novi Sad, Serbia 25 - 27 November 2015

EDITORS

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IMPACT RESISTANCE OF CONCRETE MADE WITH ADDITION MICRO FIBERS AND RECYCLED GRANULATED RUBBER

Abstract: Impact resistance of concrete represents the quantity of absorbed energy which characterizes its ability to resist failure due to dynamic loads. The paper presents the effects of adding micro-fiber (polypropylene and steel) and granulated recycled rubber to concrete on its performances in the hardened state and on its impact resistance. For the testing purposes, six batches of concrete were made. The testing results demonstrated that the addition of polypropylene and steel fibers to a considerable extent contributed to increase of the impact resistance of concrete, while the addition of recycled granulated rubber contributed to increase of the capacity of concrete to absorb energy of impact loads before the onset of first cracks.

Key words: impact resistance, concrete, recycled granulated rubber, polypropylene fibers, steel fibers

UDARNA OTPORNOST BETONA SPRAVLJENOG SA DODATKOM MIKROVLAKANA I RECIKLIRANE GRANULISANE GUME

Rezime: Udarna otpornost betona predstavlja količinu apsorbovane energije kojom se karakteriše njegova sposobnost da se odupre lomu usled delovanja dinamičkog opterećenja. U radu je prikazan uticaj dodavanja mikrovlakana (polipropilenskih i čeličnih) i granulisane reciklirane gume betonu na njegove performance u svežem i očvrslom stanju, kao i na njegovu udarnu otpornost. Za potrebe istraživanja napravljeno je ukupno šest serija betona. Rezultati ispitivanja su pokazali da je dodatak polipropilenskih i čeličnih vlakna u značajnoj meri doprineo povećanju udarne otpornosti betona, dok je dodatak reciklirane granulisane gume doprineo povećanju sposobnosti apsorbcije energije betona usled udarnog opterećenja pre pojave prve prsline.

Ključne reči: udarna otpornost, beton, reciklirana granulisana guma, polipropilenska vlakna, čelična vlakna.

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1. INTRODUCTION

Concrete is brittle material, where the degree of brittleness increases as its strength increases. It is generally accepted that the ductility of concrete can be improved by adding various types of fibers to the cement mixtures. Adding fibers to concrete increases its ductility, tensile strength, flexural strength and resistance against dynamic and impact loads [1-2]. Steel and polypropylene fibers are the most used 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 [3]. Marar et al. [2] 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. [4] 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. [5] 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. [6] 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 [7-8].

Past research has suggested that rubberized concrete could prove to be an ideal material for energy absorption [9-10]. Adding shredded rubber to concrete softens the concrete, yielding greater plastic deformation on impact and smaller deceleration forces [9-11].

The paper presents the effects of adding micro-fiber (polypropylene and steel) and granulated recycled rubber to concrete on its performances in the hardened state and on its impact resistance.

2. DETAIL OF THE EXPERIMENT

2.1. Materials used in the experiment

The reference concrete was produced with the Portland cement CEM I 42.5 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.

Four types of fibers were used for production of micro-reinforced concretes: polypropylene fibers FIBRILs S120 and FIBRILs F120 produced by "Motvoz" Grosuplje from Slovenia, steel fibers ZS/N 0.5x30 mm and ZS/N 1.05x50 mm, produced by "Spajic" d.o.o. Company Negotin from Serbia. The steel ZS/N 0.5x30 mm and ZS/N 1.05x50 mm fibers 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 and the polypropylene fibers of FIBRILs F120 type belong to the group of fibrillated fibers of rectangle cross sections and smooth surface. The fibers characteristics are given in the table 1.

Table 1- Characteristics of polypropylene and steel fibers

	Polypropylene fibers		Steel fibers	
Characteristic	FIBRILs S120 (monofilament fibers)	FIBRILs F120 (fibrillated fibers)	ZS/N 0.5x30 mm (hook ended fibers)	ZS/N 1.05x50mm (hook ended fibers)
Fiber length	12 mm	12 mm	30 mm	50 mm
Diameter (equivalent)	0.037 mm	0.45 mm	0.50 mm	1.05 mm
Aspect ratio	324	27	60	48
Tensile strength	300,7±31,7 N/mm^2	274,0±26,9 N/mm^2	1100±165 N/mm^2	1100±165 N/mm^2

The recycled rubber used was a fraction 0.5-4 mm by the „Tigar" Pirot manufacturer. Particle density and bulk density of rubber aggregate in the loose state were determined according to SRPS B.B8.031:1982 and SRPS B.B8.030:1982 and amounted to 1150 kg/m^3 and 480 kg/m^3, respectively. Also used was water reducer SIKA Viscocrete 3070.

2.2. Concrete mixture composition

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 *R* was made with 10% of rubber substitute instead of the river aggregate. The aggregate substitution was performed by volume.

The mixture marked with *PM* was made with addition of polypropylene monofilament fibers FIBRILs S120, *PF* with addition of polypropylene fibrillated fibers FIBRILs F120, *S30* with addition of steel hook ended fibers ZS/N 0.5x30 mm and *S50* with addition of steel fibers with hook ended fibers ZS/N 1.05x50 mm. The particle size distribution of basic fractions of aggregates was the same for all the mixtures, with the minimum difference for those mixtures in which a part of fine river aggregate was replaced with recycled granulated rubber. The mixtures were made with the same water /cement ratio ω_c = 0.45 and with approximately same consistency of concrete (slump 90 - 110 mm) which was achieved using superplasticizer. The compositions of the concrete mixtures are given in the table 2.

Table 2- Composition of 1m^3 of concrete mixtures used in the experiment

Series of specimen	Aggregate			Rubber	Cement	Water	Sika VSC 3070	Polypropylene fibers		Steel fibers	
	0/4 mm	4/8 mm	8/16 mm					Fibrils S 120	Fibrils F 120	ZS/N 0.5x30	ZS/N 1.05x50
	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3
E	806	447	537	-	400	177,6	2,40	-	-	-	-
R	631	449	540	78	404	178,8	3,03	-	-	-	-
PM	806	447	537	-	400	177,4	2,60	0,91	-	-	-
PF	808	448	538	-	401	177,9	2,60	-	0,91	-	-
S30	803	446	536	-	399	176,8	2,80	-	-	25,0	-
S50	801	445	534	-	398	176,3	2,80	-	-		25,0

3. EXPERIMENTAL RESEARCH

The impact resistance of concrete was tested by the so called. „Drop-weight test" according to the recommendations of professor Ukrainczyk [12] – adapted to the requirements of fiber reinforced concretes. A similar test was performed in the paper [13]. 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.

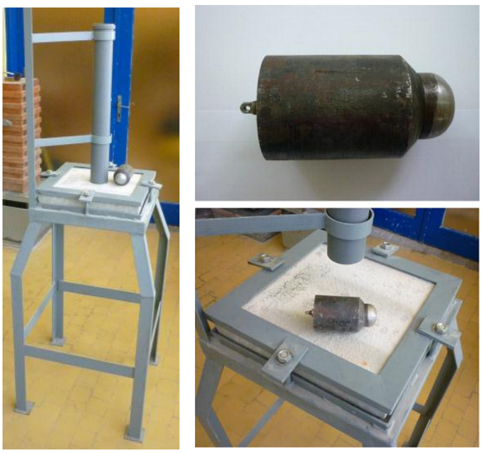

Figure 1 – Test setup of concrete impact resistance testing by the „Drop-weight" method

The criterion for evaluation of the testing results is related to the number of weight impacts until the onset of the first crack (N_1), as well as to the number of weight impacts until the failure of the slab (N_2). 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 (E_1), i.e. the total energy corresponding with the failure of the material (E_2) according to the formula:

$$E_N = N \cdot E = n \cdot m \cdot g \cdot h [J] \tag{1}$$

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 ($h=0{,}30\ m$).

The consistency was measured on the fresh concrete by the slump test according to SRPS ISO 4109:1997, the bulk density according to SRPS ISO 6276:1997 and air content of freshly mixed concrete according to SRPS ISO 4848:1999. The compressive strength and bulk density of hardened concrete were tested on the cubes with 150 mm sides according to SRPS ISO 4012:2000, the flexural strength on the prisms with dimensions 100 x 100 x 400 mm according to SRPS ISO 4013:2000, the tensile splitting strength on cylindrical cores Ø150×300 mm according to SRPS ISO 4108:2000.

4. RESULTS OF EXPERIMENTAL RESEARCH

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

Table 3- Characteristics of concrete in fresh state

Series of specimen	Density [kg/m^3]	Slump class	Air content [%]
E	2370	S3 (110 mm)	3,1
R	2285	S3 (105 mm)	4,1
PM	2370	S3 (100 mm)	3,5
PF	2375	S3 (95 mm)	3,6
S30	2390	S2 (90 mm)	3,4
S50	2385	S3 (100 mm)	3,3

Table 4- Characteristics of concrete in hardened state

Series of specimen	Density [kg/m^3]	Compressive strength [MPa]		Flexural strength [MPa]	Splitting tensile strength [MPa]	The energy consumed for the onset of the first crack [J]	The energy consumed for the failure [J]
		28 days	90 days				
E	2364	45,23	60,89	5,68	4,71	88,3	185,43
R	2274	33,11	43,78	4,72	3,67	114,79	158,94
PM	2364	45,56	63,23	6,04	5,36	132,45	291,39
PF	2367	42,67	63,78	6,12	5,30	150,11	309,05
S30	2380	44,11	64,11	6,22	5,44	220,75	> 353,20
S50	2376	43,56	63,11	6,08	5,24	194,26	309,05

5. DISCUSION OF RESULTS AND CONCLUSION

As it can be seen in table 3, the highest demand for superplasticizer, so that the planned slump could be achieved, was observed in the concrete mix in which partial replacement of fine river aggregate with granulated recycled rubber was performed. It is a logical consequence of reduction of aggregate particles below 0,5mm, because the replacement of the natural aggregate fraction 0-4 mm was done by the recycled granulated rubber having fraction 0,5-4 mm. It can also be seen in the table 3 that for each type of concrete mixes, there was an increased demand for superplasticizer if the concretes were micro-reinforced, more so in case of the concretes with steel fibers.

Based on the test results provided in table 3, it can be concluded that partial replacement of fine river aggregate with recycled granulated rubber to great extent influenced the reduction of density of compacted fresh concrete (amounting to 3,59% in comparison to the reference concrete). The reason for this is far lower density of recycled granulated rubber (1150kg/m^3) in comparison to the density of fine river aggregate (2630kg/m^3), as well as somewhat higher percentage of air content in fresh concrete mixture (table 4). The addition of polypropylene fibers, had a negligibly lower effect on the variation of density of compacted fresh concrete.

Based on the test results provided in table 3, it can be concluded that the partial replacement of the natural fine aggregated with recycled granulated rubber caused the increase of air content of fresh concrete. This is explained by the fact that in the concrete mixture there is a lack of small particles of 0,5mm which could fill the empty space between the coarse aggregate grains, because the replacement of the natural aggregate of fraction 0-4 mm was performed by the recycled granulated rubber fraction of 0,5-4 mm. The addition of polypropylene and steel fibers had only a small influence on the variation of air content in fresh concrete, which was negligibly increased. This effect was more prominent in case when higher quantity of fibers is added (regardless of their kind and type).

Partial replacement of fine river aggregate with granulated recycled rubber contributed to the significant decrease of compressive strength. Analyzing the obtained results in the table 4, it was stated that in case of the concretes with rubber, the decrease of compressive strength in respect to the reference concrete is 23,5% at the age of concrete of 28 days, i.e. 28,1% at the age of 90 days. As for the reinforcement of concrete with microfibers, it can be said that both polypropylene and steel fibers provided a small contribution to the increase of compressive strength. The polypropylene monofilament fibers contribution to the increase of compressive strength amounted to 0,8% (3,8%), while the contribution of the polypropylene fibrillated fibers amounted to 2,1% (4,8%) at the concrete age of 28 (90) days. As for the hook ended steel fibers, the short fibers contribution to compressive strength amounted to 0,6% (5,3%), while the long fibers contribution amounted to 3,2% (3,7%) at the age of concrete of 28 (90) days.

As it is already known, the addition of fibers to the concrete should primarily provide higher tensile strength of concrete, as it was confirmed in this paper based on the test results presented in table 4. As in case of the concretes made with partial replacement of fine river aggregate with recycled granulated rubber, the obtained values of flexural strength were expectedly lower than in the case of the reference concrete. Partial replacement of the river aggregate with the granulated recycled rubber in concrete contributed to the drop of flexural strength in the amount of 16,9%. As for the reinforcing of concrete with microfibers, the polypropylene monofilament fibers contributed to the flexural strength increase of 6,3%, while the polypropylene fibrillated fibers contribution amounted to 7,8%. In case of the steel fibers with hooked ends, the short fibers contributed to the increase of flexural strength of 9,5%, while the long fibers contribution amounted to 7,0%.

Partial replacement of fine river aggregate with granulated recycled rubber in concrete contributed to the decrease of splitting tensile strength of 22,1%. As for the micro reinforced concrete, the polypropylene monofilament fibers contributed to the increase of splitting tensile strength in the amount of 13,8%, while the contribution of polypropylene fibrillated fibers amounted to 12,5%. In case of the hook ended steel fibers, the short fibers contributed to the increase of splitting tensile strength in the amount of 15,5%, while the long fibers contribution amounted to 11,3%.

Partial replacement of fine river aggregate with granulated recycled rubber in concrete provides to concrete higher absorption capacity of impact load prior to the onset of the first crack. After the initial damage is made, the crack propagation is accelerated, and the sample fails after a lower number of weight impacts. This is explained by the fact that rubber has better capacity to absorb impacts and vibrations than concrete, so by being present in the concrete composite, it makes the composite surface more elastic. Due to the increased elasticity of the concrete surface, the kinetic energy of the weight after the initial impacts is transformed into the elastic deformation of the sample, while only a small portion of that energy is expended to creation of permanent deformation of concrete. After the onset of the first crack, the damage propagation is accelerated due to the weaker tensile forces in the concrete composite with granulated rubber (as confirmed by the tensile strength tests).

Fiber reinforced concretes are more resistant to impact load in comparison to the non-reinforced concretes, regardless of the type of added fibers. Steel and propylene fibers contributed to the increase of impact resistance of concrete both in the terms of increase of absorbed energy until the onset of an initial damage (first cracks) and in the sense of maintaining serviceability during a protracted period of exposure to impact loads after the onset of the first crack. Steel hooked-end fibers contributed more to this type of concrete strength than the polypropylene ones, whereby the concretes with short steel fibers demonstrated better results than the concretes with long steel fibers. Namely, the steel fibers are better anchored in the cement matrix than the polypropylene ones, due to their length and fiber ends geometry, thus they are able to take on and absorb the impact load to a greater extent. Owing to their more homogenous distribution within the concrete composite, the short steel fibers with hooked ends provide a better contribution to the increase of impact resistance of concrete in comparison to the long fibers. As for the polypropylene fibers, monofilament fibers provided a slightly smaller contribution to the increase of impact resistance of concrete in comparison with the fibril ones. The quantity of necessary energy for creation of the first crack of fiber reinforced concretes was 50-80% higher than the energy expended when testing the reference concrete, while in case of concretes reinforced with steel fibers, that energy was 120-175% higher. On the other hand the amount energy required for breaking the sample made with the addition of polypropylene fibers was for 55-85% higher than the energy expanded for breaking the reference concrete sample. In case of concrete with steel fibers, the amount of energy expended for breaking the sample was 65-100% and more than the energy required for breaking the reference concrete sample. Some of the concrete samples reinforced with steel fibers did not fail even after 40 weight impacts.

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