DRUŠTVO ZA ISPITIVANJE I ISTRAŽIVANJE
MATERIJALA I KONSTRUKCIJA SRBIJE

SOCIETY FOR MATERIALS AND
STRUCTURES TESTING OF SERBIA

MEĐUNARODNI SIMPOZIJUM

O ISTRAŽIVANJIMA I PRIMENI SAVREMENIH DOSTIGNUĆA U GRAĐEVINARSTVU U OBLASTI MATERIJALA I KONSTRUKCIJA

INTERNATIONAL SYMPOSIUM

ABOUT RESEARCH AND APPLICATION OF MODERN ACHIEVEMENTS IN CIVIL ENGINEERING IN THE FIELD OF MATERIALS AND STRUCTURES

ZBORNIK RADOVA
PROCEEDINGS

XXV Kongres - Tara, 19-21. oktobar 2011.
XXV Congress - Tara, October 19-21, 2011.

CIP - Каталогизација у публикацији
Народна библиотека Србије, Београд

624(082)
69(082)
666.7/.9(082)

МЕЂУНАРОДНИ симпозијум о истраживањима и
примени савремених достигнућа у
грађевинарству у области материјала и
конструкција (2011 ; Тара)
Zbornik radova / Međunarodni simpozijum o
istraživanjima i primeni savremenih
dostignuća u građevinarstvu u oblasti
materijala i konstrukcija [u okviru skupa]
Društvo za ispitivanje i istraživanje
materijala i konstrukcija Srbije, XXV
kongres, Tara, 20-21. oktobar 2011. =
Proceedings / International Symposium about
Research and Application of Modern
Achievements in Civil Engineering in the
Field of Materials and Structures [with in]
Society for Materials and Structures Testing
of Serbia, XXV Congress, Tara, October 20-21,
2011. - Beograd : Društvo za ispitivanje i
istraživanje materijala i konstrukcija
Srbije, 2011 (Beograd : Hektor print). - 535
str. : ilustr. ; 24 cm

Radovi na srp. i engl. jeziku. - Tekst ćir. i
lat. - Tiraž 150. - Napomene uz tekst. -
Bibliografija uz većinu radova. - Summaries.

ISBN 978-86-87615-02-1
1. Друштво за испитивање и истраживање
материјала и конструкција Србије. Конгрес (25
; 2011 ; Тара)
а) Грађевински материјали - Зборници b)
Грађевинске конструкције - Зборници
COBISS.SR-ID 186877196

Izdavač: **Društvo za ispitivanje i istraživanje materijala i konstrukcija Srbije**
Beograd, Kneza Miloša 9/I

Editor: **Prof. dr Vlastimir Radonjanin, dipl.inž.građ.**
Fakultet tehničkih nauka, Novi Sad

Beograd, oktobar 2011. godine

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Održavanje ovog skupa finansijski je potpomoglo, između ostalih i **MINISTARSTVO PROSVETE I NAUKE REPUBLIKE SRBIJE**, kao i **Inženjerska komora Srbije.**

S A D R Ž A J

ISTRAŽIVANJA NA PODRUČJU MATERIJALA I NJIHOVE PRIMENE

TEORIJSKA I EKSPERIMENTALNA ANALIZA KONSTRUKCIJA

ASEZMIČKO PROJEKTOVANJE I GRAĐENJE

ODRŽAVANJE I SANACIJA GRAĐEVINSKIH OBJEKATA

MATERIJALI, KONSTRUKCIJE I ŽIVOTNA SREDINA

ENERGETSKA EFIKASNOST GRAĐEVINSKIH OBJEKATA

DRUŠTVO ZA ISPITIVANJE I ISTRAŽIVANJE MATERIJALA I KONSTRUKCIJA SRBIJE
SOCIETY FOR MATERIALS AND STRUCTURES TESTING OF SERBIA

XXV KONGRES – Tara 19-21. oktobar 2011.
XXV CONGRESS – Tara October 19-21, 2011.

Dragica Lj. Jevtic[1], Dimitrije M. Zakic[2], Aleksandar R. Savic[3], Aleksandar V. Radevic[4]

PROPERTIES OF SELF COMPACTING CONCRETE REINFORCED WITH STEEL AND SYNTHETIC FIBERS

Summary: *Experimental research results of basic physical and mechanical properties of fiber reinforced self compacting concrete (SFR SCC) are presented in this paper. Besides reference SCC, two fiber reinforced mixtures were made and studied: one with steel and another one with syntetic fibers. The following properties of fresh and hardened concrete were monitored during the testing: consistency, density, compressive strength and splitting tensile strength as well as watertightness. The obtained experimental results showed improvement of technological and mechanical properties of the SCC made with addition of fibers.*
Keywords*: Self compacting concrete, steel and polypropylene fibers, superplasticizer, fresh and hardened concrete.*

SVOJSTVA SAMOZBIJAJUĆIH BETONA MIKROARMIRANIH ČELIČNIM I SINTETIČKIM VLAKNIMA

Rezime: *U radu se prikazuju rezultati eksperimentalnih istraživanja mikroarmiranih samozbijajućih betona (SFR SCC). Osim referentnog SCC betona, napravljena su i ispitana dva mikroarmiranih betona: jedan sa čeličnim i drugi sa sintetičkim vlaknima. Ovim istraživanjima su obuhvaćeni sledeći parametri: konzistencija, zapreminska masa, čvrstoća pri pritisku, čvrstoća pri zatezanju cepanjem kao i vodonepropustljivost. Dobijeni eksperimentalni rezultati pokazali su poboljšanje tehnoloških i mehaničkih svojstava samozbijajućih betona sa dodatkom vlakana.*
Ključne reči*: samozbijajući beton, čelična i polipropilenska vlakna, superplastifikator, svež i očvrsli beton.*

[1] Faculty of Civil Engineering, University of Belgrade, Bulevar kralja Aleksandra 73, 11000 Beograd, SERBIA, dragica@imk.grf.bg.ac.rs
[2] Faculty of Civil Engineering, University of Belgrade, Bulevar kralja Aleksandra 73, 11000 Beograd, SERBIA, dimmy@imk.grf.bg.ac.rs
[3] Faculty of Civil Engineering, University of Belgrade, Bulevar kralja Aleksandra 73, 11000 Beograd, SERBIA, sasha@imk.grf.bg.ac.rs
[4] Faculty of Civil Engineering, University of Belgrade, Bulevar kralja Aleksandra 73, 11000 Beograd, SERBIA, aradevic@grf.bg.ac.rs

1. INTRODUCTION

Self compacting concrete (SCC), introduced for the first time by Japanese engineers in the late 80's, represents proportioned hydraulic cement composite – concrete that, when in fresh state, can completely fill all types of framework and flow between steel reinforcement bars (see Figure 1), even very closely placed, all by itself, without any need for vibration [1]. Self compacting concrete achieves adequate compaction only through its rheological behavior in the fresh state. Beside the high grade of fluidity, which is the basic property of such concrete, SCC possesses one more important property - high segregation resistance capacity. It has the ability to resists both external and internal segregation, but aggregate settlement and bleeding as well, with no blocking effect around densely arranged re-bars.

Figure 1. L-box test, commonly used for passing ability assessment of fresh state SCC mixture (left), and an illustration of on-site behavior of SCC (right), covering densely spaced reinforcement bars

As expected, the composition of self compacting concrete differs from traditional concrete [2]. First of all, special superplasticizers, known as high range water reducing admixtures (HRWR), are needed. These are such surface active agents that enable high workability and placeability of concrete in the case when a very small amount of water is used. HRWR admixture brings about the required water reduction and fluidity, but also maintains its dispersing effect during the time required for transport and application. The required consistence retention depends on the application. Precast concrete is likely to require a shorter retention time than concrete that has to be transported to and placed on the site.

At the same time, such concrete has to be resistant to segregation of coarse aggregate and bleeding. One way to solve this problem is to increase fines (materials with particle size smaller than 0,125 mm) in order to achieve better cohesion of the mix, with the simultaneous decrease of coarse aggregate size and quantity. Therefore, the essential part of every SCC is filler - which is not commonly used as a component of traditional concrete. It magnifies the fresh concrete's ability to flow, decreases it's segregation and results in better durability, because voids between larger aggregate grains are being reduced. Moreover, aggregate used for SCC usually contains grain sizes not more than 20 mm.

Also, Viscosity Modifying Admixtures (VMA) are commonly used to increase SCC's segregation resistance. The key function of VMA is to modify the rheological properties of the cement paste. By interaction of the functional groups of their molecules with the water and the surfaces of the fines, VMA's build up a three dimensional structure in the liquid phase of the mix to increase the viscosity and/or yield point of the paste, thus providing internal segregation resistance.

Therefore, components that can be typically found in self compacting concrete are following [3]:

- higher class cements with a high value of specific surface;
- powder (fines) particles smaller then 0.125 mm;
- sand (0/4 mm);
- coarse aggregate (usually maximum size up to 16 mm);
- water;
- admixtures (HRWRA and VMA);
- mineral admixture (fly ash, silica fume, ground blast furnace slag, ground glass filler, pigments);
- fibers – micro reinforcement.

Fiber reinforced cement (FRC) composite materials are basically cement based composites made with addition of different types of fibers, which represent a special micro-reinforcement. Uniformly distributed fibers are strengthening the cement matrix, thus improving the whole set of properties of the basic material. The cement matrix can be reinforced using either metallic (steel), synthetic (polymeric), mineral (glass, stone) or natural (organic) fibers.

Essentially, the fiber-reinforcement concept is about the increment of quality of a complex composite material (mortar or concrete), by improving certain properties of fresh and hardened material, which are crucial for its practical application [4,5]. The best effects are achieved in the field of strength improvement (especially in flexure, tension and shear), as well as ductility enhancement of the above mentioned composites. Also, very good results are obtained concerning the reduction of shrinkage, as well as the improvement of fatigue and impact resistance behavior.

In the case of SCC, fiber addition can generate several new problems [6], first of all loss of workability. Absence of any kind of compaction can also lead to decrease in mechanical properties of SCC in hardened state. Proper balance of all mentioned components is of essential importance in order to optimize FR SCC's performance.

2. EXPERIMENTAL RESEARCH

In this chapter, the results of own experimental research conducted in the Laboratory for Materials at the Institute for Materials and Structures, Faculty of Civil Engineering, University of Belgrade, are presented. Three types of concrete were made and tested – one reference mixture (concrete Series '1') and two mixtures with the addition of fibers – concrete Series ‘2’ with the addition of steel fibers, and concrete Series ‘3’ with the addition of polypropylene fibers.

The steel fibers used as a fiber-reinforcement in concrete Series ‘2’ were produced in “Spajić” factory (Kobišnica, Eastern Serbia)[7]. The adopted type of fibers, with dimensions 8x0.2 mm (aspect ratio l/d = 40), used in quantity of 20 kg/m3 (app. 0.20% of volume). Basic properties of these fibers are presented in Table 1 and Figure 2 shows the shape of fibers.

Figure 2. The display of used fibers

Table 1. The properties of “Spajić” steel fibers

Parameters	Declared Properties
Tensile strength	app. 3000 MPa
Melting point	app. 1500°C
Length	30±2 mm
Thickness	0.2±0.025 mm
Angle of bending	min. 45°
Cross section	Round
Chemical composition (%)	
C	0.80
Mn	0.80
P	0.035
S	0.035
Si	0.30

The polypropylene fibers used as reinforcement in concrete Series ‘3’ were produced by Sika Hellas ABEE - Athens. Fibers used in this research were 12 mm long. The fibres are coated with surfactant to improve initial dispersion within the cementitious materials. Basic properties of these fibers are presented in Table 2.

Table 2. Basic properties of used polypropylene fibers

Parameters	Declared Properties
Chemical base	Polypropylene (100 %)
Fibers type	Monofilament
Cross section	Round
Diameter	25 μm (±10%)
Length	12 mm (±10%)
Shape factor (l/d)	480
Density	4.4 Dtex (±10%) (EN ISO 13392)
Tensile strength	400 MPa (EN ISO 2062)
Elongation at Break	25% (±10%) (EN ISO 2062)
Elasticity modulus	1600 MPa
Softening point	160 °C
Recommmended dosage	600 – 900 g/m3

These monofilament polypropylene fibres reduce the occurrence of plastic shrinkage and plastic settlement cracking, whilst enhancing the surface properties and durability of hardened cementitious products. They show best performance when used in:

- plates, slopes, wide concrete surfaces,
- concrete and mortars under shocks,
- mortar or concrete used as a screed,
- precast industry (in order to improve performance and durability in corners),
- coatings, plasters.

3. RESULTS AND DISCUSSION

The research included concrete mix design based on cement, limestone mineral filler and river aggregate (separated in three standard fractions), steel and polypropylene fibers, as well as a special type of superplasticizer. Mineral filler used for this research is produced by Peščar Granit, Ljig. Admixture named MC Bauchemie Powerflow 2240 was applied. Quantity of this admixture was 2.4% of the cement mass. Cement type PC 20M (S -L) 42.5 R “Lafarge” Beočin was used in this research.

In order to examine the properties of fiber reinforced SCC, three concrete mixes (Series marked as 1, 2 and 3, see Table 3), as it was already mentioned) with the constant quantity of cement (410 kg/m^3) were made. Quantity of limestone mineral filler amounted to 104 kg/m^3 was also constant. Quantities of aggregate were constant in all three mixes (1627 kg/m^3). Quantity of steel fibers in mixture ‘2’ was 20 kg/m^3, while the quantity of polypropylene fibers in mixture ‘3’ was 750 g/m^3. These quantities of fiber reinforcement were set as the most common in fiber reinforced concrete [9,10]. Target

SCC flowability was defined as SF1. Namely, according to European guidelines for SCC [2], there are three possible classes of SCC, regarding it's flowability:

- SF1 (550 - 650 mm), which is appropriate for unreinforced or slightly reinforced concrete structures that are cast from the top with free displacement from the delivery point (e.g. housing slabs), casting by a pump injection system (e.g. tunnel linings) and sections that are small enough to prevent long horizontal flow (e.g. piles and some deep foundations),

- SF2 (660 - 750 mm), which is suitable for many normal applications (e.g. walls, columns),

- SF3 (760 – 850 mm), which is typically produced with a small maximum size of aggregates (less than 16 mm) and is used for vertical applications in very congested structures, structures with complex shapes, or for filling under formwork. SF3 will often give better surface finish than SF2 for normal vertical applications but segregation resistance is more difficult to control.

Table 3. Mix designe of concrete

Series / Mix composition		1	2	3
	Gravity (kg/m3)	Amount (kg/m^3)	Amaunt (kg/m^3)	Amaunt (kg/m^3)
Cement PC 20M(S-L) 42.5R	3100	410	410	410
Filler (limestone flour)	2380	104	104	104
Water	1000	183	183	183
I fraction	2600	693	693	693
II fraction	2605	398	398	398
III fraction	2604	536	536	536
Chemical admixture MC PowerFlow 2240	1060	9.67	9.67	9.67
Steel fibers	7800	-	20	-
Polypropylene fibers	900	-	-	0.75

Target values higher than 850 mm may be specified in some special cases but great care should be taken regarding segregation, and the maximum size of aggregate should normally be lower than 12 mm.

During the mixing process, quantity of water was held constant in order to sustain the same target consistency defined as SF1 in all three mixtures. Tests on fresh SCC included: slump-flow test and T500 measurement (two tests used to assess the flowability and the flow rate of self-compacting concrete in the absence of obstructions), as well as V-funnel (used to assess the viscosity and filling ability of self-compacting concrete) test. Illustration of these tests is given on Figure 3. Average density of concrete in fresh state was also measured. All the data regarding mentioned tests are presented inside Table 4.

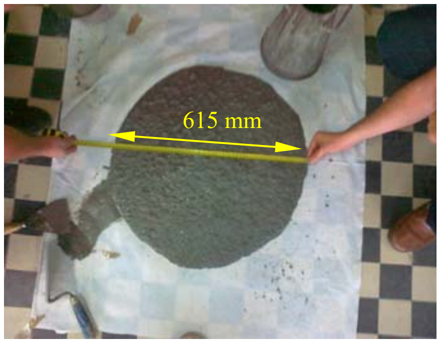

Figure 3. T500 test – time until fresh concrete reaches diameter of 500 mm is measured (left) and V-funnel test where the time needed for all of the concrete to fall out of funnel (right) is measured

Table 4. Results of parameters measurement on fresh state concrete

Concrete mixture Series	Slump flow test [mm]	T500 [s]	V-funnel [s]	Fresh concrete density [kg/m3]
'1'	650	3.5	8	2351
'2'	615	3.0	8.1	2339
'3'	615	3.6	8.1	2320

As it is shown in the Table 4, all of these concrete types can be classified as slump flow (SF) class SF1, having the largest diameter of the flow spread between 550 and 650. Evaluation of the viscosity and filling ability of SCC according to T500 and V-funnel tests was not clear, as methods pointed to different classes (see Table 5) [3].

Table 5. Viscosity classes according to T500 and V-funnel tests

Class	T500 [s]	V-funnel time [s]
VS1/ VF1	≤ 2	≤ 8
VS2/ VF2	> 2	9 to 25

Compressive strength tests were performed on cube shaped specimens (with an edge size of 15 mm), at the age of 3, 7, 28 and 90 days, while the splitting tensile strength and watertightness was measured only at 28 days.

Table 6. Properties of hardened concrete

	Compressive strength (MPa)				Splitting tensile strength (MPa)	Watertightness (mm)
Series \ Age (days)	2	7	28	90	28	28
1	28.10	46.10	53.20	70.00	3.42	15
2	31.90	45.75	56.55	72.90	3.47	11
3	30.10	43.55	54.20	66.70	3.14	13

4. CONCLUSIONS

Based on the results of FR SCC research, it can be concluded that the compressive strength of all three SCC concretes amounted to approximately 30.0 MPa at the age of 2 days, 45.1 MPa at the age of 7 days, 54.6 MPa at the age of 28 days and 69.9 MPa at the age of 90 days (Fig. 4.).

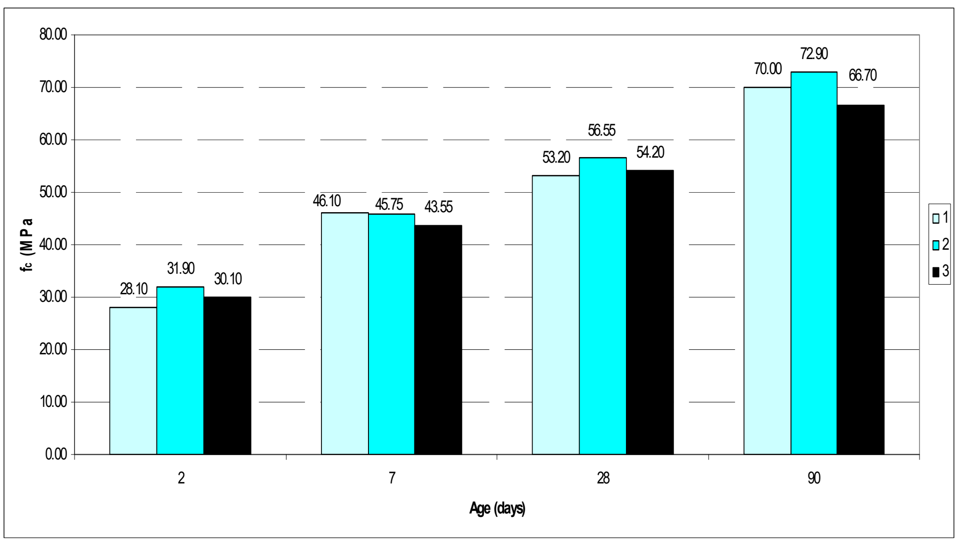

Figure 4. Compressive strength evolution of concrete

Splitting tensile strength amounted to 3.42 MPa (for concrete Series "1"), 3.47 MPa (for concrete Series "2") and 3.14 MPa (for concrete Series "3") at the age of 28 days.

Results presented in this paper showed that minimum amount of steel fiber reinforcement (20kg/m^3) added to the SCC mixture didn't decrease the performance of the concrete in terms of consistency, but did improve mechanical properties, substantialy. Improvement of compressive strength was 5.9% at the age of 28 days, compared to the reference mixture, and 4.0% at the age of 90 days. Splitting tensile strength at the age of 28 days, on the other hand, improved 1.4%, as a result of steel fiber addition in SCC.

It is evident that compressive strength continued to increase even after 28 days, which can be attributed to the pozzolanic effect of slag in the cement. The compressive strenght measured after 90 days increased 32%, 29% and 23% for series 1, 2 and 3, respectively, in comparison to that after 28 days.

Research made on fresh SCC concretes showed a slight decrease of workability with the addition of fibers, but the viscosity classes according to T500 and V-funnel tests remained in the same limits.

Due to their high mechanical strengths and presence of fibers, these composites can be successfully used, both for the new buildings as well as for repair and reconstruction of already existing structures. The use of fiber reinforced composites is recommended in particular for buildings where not only good physical and mechanical properties are required, but also high durability and resistance of materials used.

ACKNOWLEDGEMENT

The work reported in this paper is a part of the investigation within the research project TR 36017 "Utilization of by-products and recycled waste materials in concrete composites in the scope of sustainable construction development in Serbia: investigation and environmental assessment of possible applications", supported by the Ministry for Science and Technology, Republic of Serbia. This support is gratefully acknowledged.

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