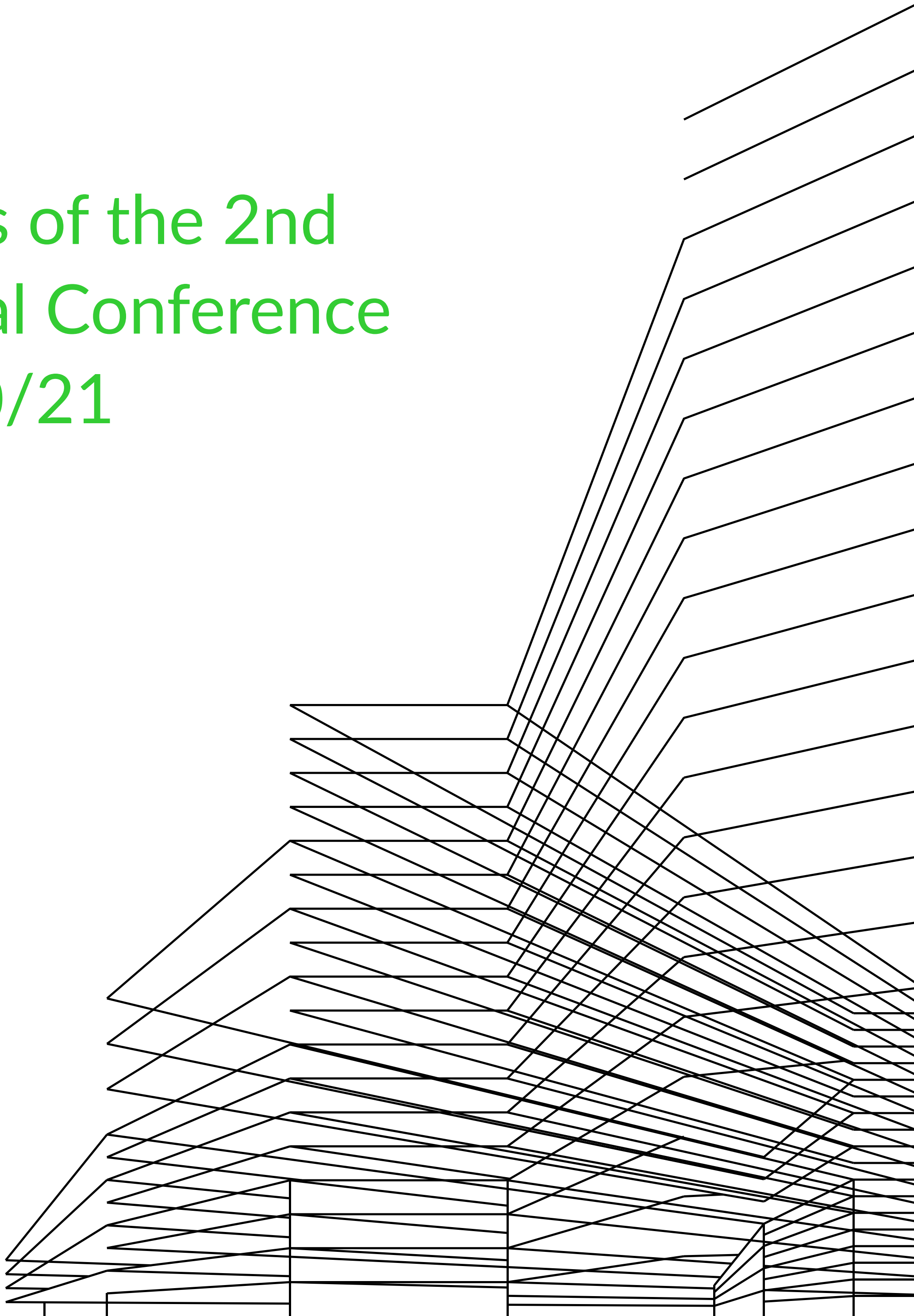
CoMS_ 2020/21

Construction Materials for a Sustainable Future



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Marko Stojanović, Ksenija Janković, Dragan Bojović, Lana Antić, Ljiljana Lončar

Influence of different types of fibers on the ultimate and residual flexural strength of sprayed concrete

INFLUENCE OF DIFFERENT TYPES OF FIBERS ON THE ULTIMATE AND RESIDUAL FLEXURAL STRENGTH OF SPRAYED CONCRETE

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SUMMARY: The influence of the application of different types of fibres on the flexural strength of beams cut from slabs of sprayed concrete is presented in the paper. Fibres of different materials, shapes and dimensions were used. All types of concrete were made of the same component materials and composition, except the amount of fibres that is varied. Slabs of dimensions 60x60x10 cm were made using a concrete spraying machine. After curing, the beams of 75x125x500 mm were cut from the beams. Flexural strength of the beams was tested according to SRPS EN 14488-3 at the age of 28 days. Based on the test results, depending on the type, shape, amount and distribution of fibres, values of ultimate and residual strengths were analysed. The highest values of ultimate and residual strength at deformations of 0.5-1, 0.5-2 and 0.5-4 mm had sprayed concrete (or shotcrete) with the addition of 40 mm polypropylene fibres.

KEY WORDS: shotcrete, fibres, flexural strength, ultimate and residual strength.

1 INTRODUCTION

Shotcrete has been used as a protective coating of wall masses and soil surfaces that are prone to collapsing for over 50 years now. Before 1990, there wasn't much information related to the mechanical properties of shotcrete in the research papers published in scientific journals, but the academic community saw this material as an opportunity to stabilize the slopes and improve tunnel safety [1].

There are many applications of shotcrete: tunnelling, mining, slope stabilization, concrete repair, etc. It offers several advantages in industrial applications, including good substrate adhesion, the opportunity to dispense with formwork, good compaction, strength that rapidly increases during curing, and ease of application in restricted areas. Different admixtures and additions are used for regulating the required properties of the produced shotcrete [2].

However, meeting the high support requirements for the traditional wet-mix shotcrete technique is difficult, especially under the complicated geological conditions such as large geo stress and high-pressure water pouring causing shotcrete layer cracking and large rebound. Hence, a high performance wet-mix shotcrete has to be made, owning high pumpability and shoot ability and harden characteristics together. That can be performed if the mixture proportions based on the fibre reinforced shotcrete are optimized. Fibres significantly affect shotcrete properties and the addition of fibres to normal shotcrete can improve the toughness or energy absorption capacity efficiently [3-4].

The toughness of fibre reinforced sprayed concrete may be specified either by residual strength or by energy absorption class depending on the test considered to characterize the material, according to SRPS EN 14487-1:2008 [5]. For example, there were four classes of residual strength (Class S1 to S4) defined based on the results from flexural tests of beams that were sawn from sprayed panels with standardized dimensions of 75 x 125 x 500 mm and defined by SRPS EN 14488-3:2006 [6]. In cores extracted from the structure, this procedure is time-consuming, difficult, and not practical. The slab specimen test described in SRPS EN 14488-5:2006 [7] as well as some other tests, also rely on the production of test panels, which must be sprayed separately and are difficult to extract from the structure. The rebound in the panel may be very different from the real structure, so this is an important drawback. Consequently, the composition and the performance in the test panel may be different from the ones found in the structure.

In wet-mix shotcrete technique, fibres are added to the fresh concrete and the mixtures are pumped to a nozzle, where it is accelerated by compressed air so they can be sprayed onto a surface. Setting accelerator is normally added at the nozzle in order to reach the certain stiffness upon arrival on the surface area.

2 EXPERIMENTAL WORK

In this paper, three types of shotcrete were prepared, which were designed with different polypropylene fibres and one control type without fibres. Shotcrete was made with materials that are available in Serbia. Portland cement CEM I 52.5 R, manufactured by CRH - Popovac, was used. The chemical, physical and mechanical properties of the cement are shown in Table 1.

Table 1: Properties of cement CEM I 52.5R, CRH - Popovac

Chemical, %		Physical		Mechanical	
SiO_2	19.51	Specific gravity, kg/m^3	3120	Compressive strength, N/mm^2	
Al_2O_3	5.12	Specific surface, cm^2/g	4180	2 days	34.5
Fe_2O_3	2.53	Standard consistency, %	30.2	28 days	59.5
CaO	63.74	Setting time, min		Flexural strength, N/mm^2	
MgO	2.45	Initial	150	2 days	7.1
Na_2O	0.22	Final	200	28 days	9.9
K_2O	0.71	-	-	-	-
SO_3	2.90	-	-	-	-
Cl^-	0.004	-	-	-	-

Crashed, fractionated stone aggregate with the maximum grain size of 8 mm was used. Specific gravity of fine and coarse aggregates was 2710 kg/m^3 and 2720 kg/m^3 respectively. Water absorption of fine aggregate is 1.2%, and for coarse aggregate it is 0.9%.Polypropylene fibres "Sika fibre PM-39" and “Sika fiber T-40” - Sika, were used in the research. The properties of the fibres are shown in Table 2.

Table 2. Properties of the polypropylene fibres

Properties	Sika fiber PM-39	Sika fiber T-40
Material	Polypropylene 100%	Polypropylene 100%
Design	Monofilament	Monofilament
Specific gravity	0.91 g/cm^3	0.91 g/cm^3
Equivalent diameter	0.70 – 0.73 mm	0.78 mm
Length	39 mm	40 mm
Aspect ratio	85	67
Alkali resistance	Excellent	Excellent
Tensile Strength	448 MPa	600 MPa
Modulus of elasticity	3600 - 3700 MPa	2500 MPa
Chemical resistance	Excellent	Excellent
Melting point	165°C	160°C
Ignition point	>360°C	590°C

In this research, used Sika admixture: "Sika Techno 20S" superplasticizer, with a specific gravity of 1060 kg/m^3, and the recommended dosage of 0.6 %; "Sigunit L5601AF" set accelerating admixture, with the specific gravity of 1040 kg/m^3, and the recommended dosage of 3.5 %, produced by Sika, were used. Three types of shotcrete samples were made: control concrete without fibres and shotcrete with the addition of 4 kg/m^3 of two types of polypropylene fibres. A "dry process" was used to prepare the basic mix of shotcrete. The shotcrete mixtures were given in Table 3.

Table 3. Mixtures of shotcrete

Materials		Reference without fibres	Sika fibres PM 39	Sika fibres T40
Cement (kg/m3)		420	420	420
Aggregate (kg/m3)	0/4mm – 70%	1066	1066	1088
	4/8 mm – 30%	458	458	583
Mineral supplement - limestone		160	160	160
Superplasticizer (kg/m3)		2.52	2.52	2.52
Set accelerating admixture (kg/m3)		14.7	14.7	14.7
Water (kg/m3)		210	210	210
Polypropylene fiber (kg/m3)		0	4	4
w/c		0.5	0.5	0.5

Prismatic beam specimens were subjected to a bending moment by the application of load through upper and lower rollers. The first peak, maximum and residual loads sustained are recorded and the corresponding flexural strengths calculated.

A fibre reinforced prism specimen, sawn from a test panel in accordance with EN 14488-1 was subjected to a bending moment by the application of load through upper and lower rollers under deflection control to obtain its load/deflection response (the latter exclusive of non-bending deformations). The first peak, ultimate and residual flexural strengths are determined from the load/deflection curve [6].

The application of load through upper and lower rollers made the prismatic beam specimens subjected to a bending moment. The first peak, maximum and residual loads sustained were recorded and the corresponding flexural strengths were calculated. All test specimens were cut from a sprayed panel into sawn prisms with dimensions of 75 mm x 125 mm x 500 mm, as shown in Figure 1, and prepared to meet the requirements of EN 12390-1. The bottom uncut mould face should be identified on the specimen (indicating the direction of spraying).

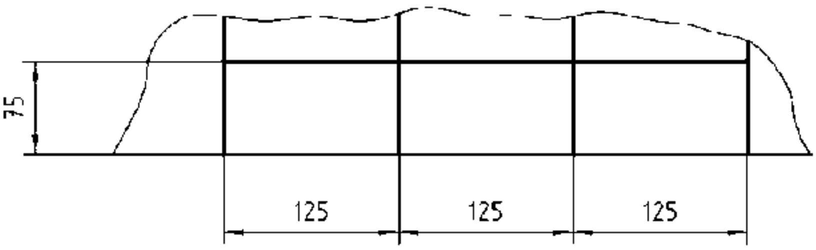

Figure 1: Cutting arrangement for beams [5].

The disposition of the beam test is shown in Figure 1. Beams were tested at 28 days of age. The distance, l, between the outer rollers (i.e. the span) was 450 mm, and the distance between the inner rollers was 150 mm. The inner rollers were equally spaced between the outer rollers as shown in Figure 2. All rollers were adjusted to the positions illustrated in Figure 2.

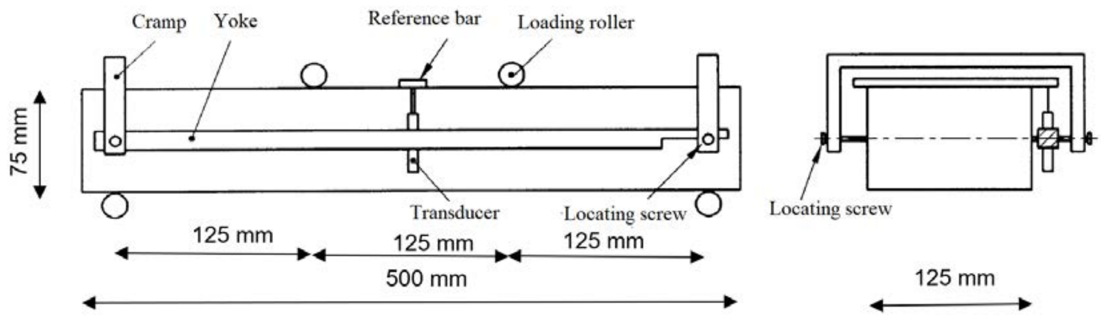

Figure 2: Disposition of the beam for bending deflection measurement

3 RESULTS AND DISCUSSION

For the flexural strength testing of concrete, beams with dimensions of 75 mm x 125 mm x 500mm and a digital hydraulic press with the range of 300kN were used. At the top of the beam, an inductive displacement meter LVDT is placed in the central part.

The load was constantly applied by a digital hydraulic press. Flexure strength testing for each type of shotcrete was performed on three samples. The obtained values for each type of shotcrete are shown in the diagram as the mean of three tests. Considering that the samples were obtained by cutting from the same plate, the variation of the results is minimal. The minimum value of force was obtained with concrete that was not reinforced with fibers (Control beam). The maximum fracture force of 6.0 kN was achieved at a beam deformation of 0.132mm. The beams were broken in half lengthwise.

The shotcrete samples reinforced with PM 39 fibers reached a maximum value of 7.1 kN at a deformation of 0.207 mm. In this condition, a crack formed on the underside of the beam. The bending force from the concrete is transmitted to the fibers. In the part of the diagram after the maximum force, the force decreases to the value of 7.012 kN at a deformation of 0.364 mm. The concrete cross-section of the beam loses its load-bearing capacity and the entire load is taken over by the fibers. The fibers maintain a force of 0.52kN with a beam deformation of 0.4mm and up to 4mm.

The obtained load - deflection diagram is very similar in shotcrete reinforced with T 40 fibers. Beams exposed to bending reached a maximum force value of 7.8 kN at a deformation of 0.278 mm, when the first crack and weakening of the cross section formed. Concrete withstood load up to 6kN and a deformation of 0.4 mm when the entire load was taken over by fibers with values of 0.61mm and up to 4mm.

Load – deflection diagrams are shown in Figure 3.

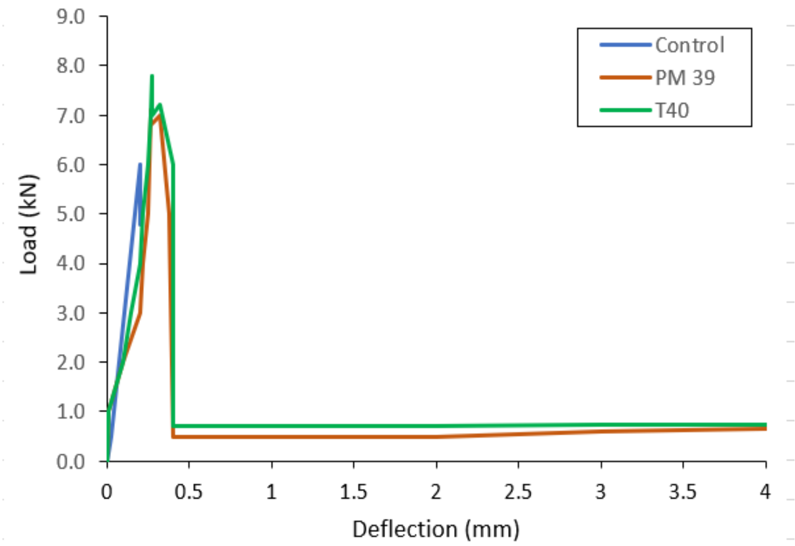

Figure 3: Diagrams of load-deflection curves for the determination of first peak load P_{f_p}

Based on the calculation formula according to SRPS EN 14488-3, the ultimate flexural strengths in N/mm^2 were obtained. Residual deformation strengths of 1, 2 and 3 mm beams were less than 1 MPa except for the control fiber-free concrete. The obtained test results are shown in Table 4.

Table 4 - Test results for shotcrete beams at the age of 28 days

	Maximal load	Ultimate flexural strength	Residual flexural strength			X
	P_{ult}	f_{ult}	f_{r_1}	f_{r_2}	f_{r_3}	
	kN	N/mm^2	N/mm^2			mm
Control - without fibers	6.0	3.9	-	-	-	22.5
Beam with Sika fibers PM 39	7.1	4.5	<1	<1	<1	22
Beam with Sika fibers T 40	7.8	5.0	<1	<1	<1	21

4 CONCLUSIONS

Based on the results obtained from testing the fibre reinforced concrete beams, the following can be concluded:

- Control beam (shotcrete without polypropylene fibres) had lower load compared to other concrete mixes and brittle fracture,
- Beams with polypropylene fibres Sika fibres PM 39 had achieved maximum load of 7.1 kN and ultimate flexural strength of 4.5 N/mm^2,
- The highest load was obtained for shotcrete with 4kg/m^3 polypropylene Sika fibres T-40. The fibres were well distributed and oriented in the cement matrix, the maximum load was 7.1kN and ultimate flexural strength 5.0 N/mm^2,
- Beams reinforced with polypropylene fibres had residual flexural strengths of less than 1 N/mm^2.

Both types of shotcrete with fibres (Sika fibres PM 39 and T 40) were D1S4 residual strength class according to SRPS EN 14487-1:2005.

The obtained test results suggest that a slight advantage can be given to Sika fibre T-40 fibres. Beams with these fibres achieved higher maximum load, ultimate flexural values and ultimate flexural strength.

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