THE INFLUENCE OF REINFORCEMENT TYPE ON SHOTCRETE PROPERTIES FOR TUNNEL LINING

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Abstract: *This paper presents the possibility of using synthetic (polyolefin) and steel fibers in shotcrete to be used in tunnels in the production of primary coatings. In the experimental work, shotcrete slabs with and without the content of polyolefin and steel fibers, as well as slabs with constructive reinforcing mesh were made. Shotcrete slabs were tested for punching (absorption energy). Based on the results of the test it is assumed that it is possible to apply the fibers in the shotcrete during the production of the primary tunnel liner. The obtained values of the shotcrete test with the content of polyolefin fibers, have met the favorable mechanical properties.*

Keywords: *shotcrete, fiber reinforcement, energy absorption*

1. INTRODUCTION

"Shotcreting" with compressed air is the process of applying fresh concrete mass to a horizontal, sloping or vertical surface, rock surface (in the cavity, tunnel, slope, etc.). Often, the terms "shotcrete" or "sprayed concrete" are also used. The built-in concrete is distinguished by high physical-mechanical properties (bulk density, strength, surface adhesion, waterproofness, frost resistance) as well as satisfactory durability, hence the shotcreting procedure is very widely used. [1]
For more than 50 years, shotcrete has been used as a protective coating for wall masses, soil surfaces that are prone to collapsing. Before 1990, only a few research papers were published in scientific journals with information related to the mechanical properties of

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shotcrete, which raised awareness of the use of this material to the academic community as an opportunity for improving tunnel safety and for stabilizing the slopes. [2]
The key points in designing this kind of material are to withstand the loads and deformations the ground can cause during the working life of the tunnels, to maintain adequate ground stability, and to protect the workers and the equipment from falling rock masses. [3, 4]
However, the adhesion between the rock and shotcrete is a complex issue. There is a number of factors that stimulate the properties and, therefore, the capacity and deformability of shotcrete, such as: mechanical properties of the rocks, the adhesion between the rock bolts and shotcrete and their mechanical properties, the stresses in the rock masses, and the thickness of shotcrete lining. [5, 6]
The basic goal of designing shotcrete is to create a self-supporting arc, made of shotcrete and other components for supporting the rock bolts, such as wall anchors, wire mesh and other structural reinforcement which is exposed to certain loads and deformations.
In tunnels made at great depths, the rock maintenance system should allow the permissible displacement of tunnel walls to prevent the collapse of tunnels. In this state, the relevant characteristics of the concrete shields are: its deformability at the maximum displacement and its strength during the displacement. In this case, during the tunnel design, it is not expected to accept tension around the tunnel, but it allows the deformation of the energy transfer from the rock to the shotcrete lining. [7]
Shotcrete is often made with certain specific chemical additives, as well as with micro reinforcement (usually steel or synthetic fibers). Accelerated increase in shotcrete strength, its ability to easily apply to faceted surfaces without the need for formwork, and the fact that it provides additional flexibility to the rock mass, make this process ideal for use in underground works, as well as in the field of rehabilitation.
As technology advances, the application of new technologies in construction, where there are more and more applications of the so-called "fiber reinforced shotcrete” (FRS), is also being monitored. The main difference is that there is micro reinforcement in the form of steel or synthetic fibers in FRS concrete.

2. EXPERIMENTAL WORK

In this paper, four types of shotcrete slabs with polyolefin and steel fibers are compared, compared to non-fiber shothcrete and reinforcement mesh.
The slabs were built in real conditions during the construction of the primary tunnel linings for the construction of the tunnel in the Cortanovci show on Figure 1.

Figure 1. Stabilization of the slope with shotcrete

Shotcrete was made with materials that are available in Serbia. Portland-composite cement with mixed addition of granulated slag and limestone CEM II / A-M (S-L) 42.5 R, manufactured by Lafarge BFC, was used. The chemical, physical and mechanical properties of the cement are shown in Table 1.

Table 1. Properties of cement CEM II / A-M (S-L) 42.5 R, Lafarge BFC

Chemical, %		*Physical*		*Mechanical*	
SiO_2	19.38	*Specific gravity, kg/m³*	4220	*Compressive strength, N/mm²*	
Al_2O_3	5.14				
Fe_2O_3	2.30	*Specific surface, cm²/g*	3.09	*2 days*	29.1
CaO	60.64				
MgO	2.50	*Standard consistency, %*	27.0	*28 days*	54.7
Na_2O	0.30			*Flexural strength, N/mm²*	
K_2O	0.41	*Setting time, min*		*2 days*	5.4
SO_3	3.40	*Initial*	180		
Cl^-	0.008	*Final*	240	*28 days*	8.8

Natural, river, fractionated stone aggregate with the maximum grain size of 8 mm was used.
Specific gravity of fine and coarse aggregates were 2650 kg/m^3 respectively. In addition, the fine aggregate fineness modulus was 3.16. The granulometric composition of aggregate fractions 0/4 and 4/8 mm are shown in Figure 2.

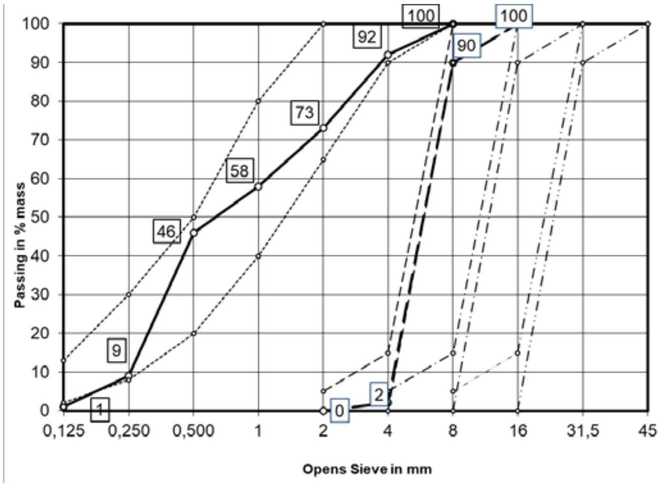


Figure 2. Gradation curves for coarse and fine aggregates used

Synthetic (polyolefin) fibers "Sika fiber T-48" – Sika and steel fibers ZS/N “Spajic” were used in the research. The fiber properties are shown in Table 2.

Table 2. Properties of the Polyolefin and steel fibers

Properties	*Values*	
Manufacturer	*Sika - Švajcarska*	*Spajić - Negotin*
Material	*Polyolefin 100%*	*Unalloyed steel ZS/N*
Design	*Monofilament*	*Fibers with reinforced ends*
Specific gravity	*0.91 g/cm³*	*7,1 g/cm³*
Equivalent diameter	*0.92 mm*	*0,50 mm*
Length	*48 mm*	*30 mm*
Aspect ratio	*52*	*60*
Alkali resistance	*Excellent*	*-*
Absorption	*Nil*	*-*
Tensile Strength	*560 MPa*	*1100 MPa*
Modulus of elasticity	*20500 MPa*	*210000 MPa*
Chemical resistance	*Excellent*	*-*
Melting point	*170°C*	*-*
Ignition point	*590°C*	*-*

Two types of admixtures were used: 1. Superplasticizer "Sika Viscocrete 4077" - Sika with a specific gravity of 1060kg/m^3, and the recommended dosage is 0.6 - 1.2%; 2. The accelerator "Sika Sigunit L72-AF" - Sika, with a specific gravity of 1040kg/m^3, and the recommended dosage is 4 - 8%.
Four types of shotcrete samples were made. Concrete was made without and with fibers, 6 kg of polyolefin, 35 kg steel fibers and Q 524 concrete reinforcement mesh.

The shotcrete mixture is given in Table 3.

Table 3. Design mix shotcrete

Material		Mix mark			
		SC1-0kg	*SC2- 6kg pf*	*SC3-35kg sf*	*SC4-Q*
Cement (kg/m3)		*420*	*420*	*420*	*420*
Aggregate (kg/m3)	*0/4mm – 70%*	*1222*	*1222*	*1222*	*1222*
	4/8 mm – 30%	*523*	*523*	*523*	*523*
Superplasticizer (kg/m3)		*3.4*	*3.4*	*3.4*	*3.4*
Accelerator (kg/m3)		*21.0*	*21.0*	*21.0*	*21.0*
Water (kg/m3)		*180*	*180*	*180*	*180*
Polyolefine fiber (kg/m3)		*-*	*6*	*-*	*-*
Steel fiber (kg/m3)		*-*	*-*	*35*	*-*
w/c		*0.429*	*0.429*	*0.429*	*0.429*

A "wet process" was used to prepare the basic mix of shotcrete. Shotcrete was made in the concrete factory Lafarge in the city of Beška. Consistency by the slump test class S4 (180-230 mm) is required.
The transport of the basic concrete mixture to the shotcrete machine was done by truck mixers. Fresh concrete is pumped out of the concrete mixer trucks into the basket of the shotcrete machine, where by pressing the fresh concrete it is carried out to the nozzles where it is mixed with the accelerator, after which it is thrown out of the nozzle under great pressure and is deposited in several layers to the surface.

3. RESULTS AND DISCUSSION

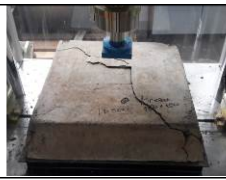
The consistency of the fresh basic mix design shotcrete was class S4 according to standard SRPS ISO 4103.
For the testing of shotcrete slabs for absorption energy according to SRPS EN 14488-5, specimens 60x60x10cm were sampled according to SRPS EN 14488-1.
Samples of shotcrete were built in by a shotcreting machine into slab shaped metal molds with the dimensions of 60x60x10 cm. The construction of the primary tunnel lining is shown in the Figure 3.

Figure 3. Making shotcrete in metal moulds and test samples

For the puncture testing of concrete slabs 600x600x100 mm, a digital hydraulic press with the range of 300kN was used. During testing, a steel frame of 500x500 mm was used. Under the slab, an inductive displacement meter LVDT is placed in the central part. Disposition tests as well as testing slabe according to EN 14889-5 is shown in Table 4.

For the puncture testing of concrete slabs 600x600x100 mm, a digital hydraulic press with the range of 300kN was used. During testing, a steel frame of 500x500 mm was used. Under the slab, an inductive displacement meter LVDT was placed in the central part. Disposition tests as well as testing slabe according to EN 14889-5 is shown in Table 4.

Table 4. Disposition tests as well as testing slab according to EN 14889-5

Shotcrete	Shotcrete with *polyolefine fiber*	Shotcrete with *steel fiber*	Slab shotcrete with *reinforcing mesh*
			
			
			

After the completion of the test, a diagram load - deflection shown in Figure 4 was obtained.

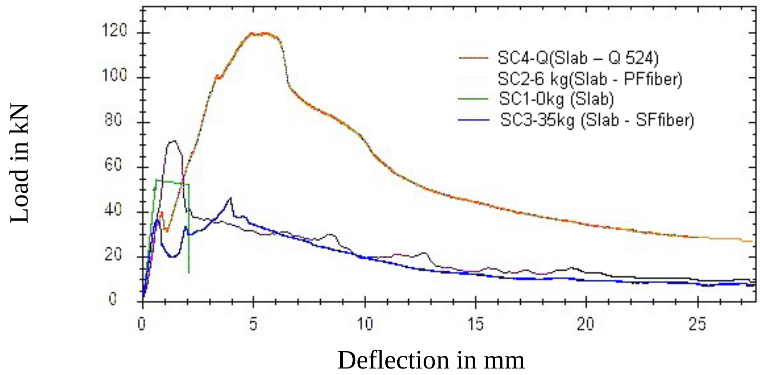


Figure 4. Chart load / deflection during the examination of the slab made of fiber reinforced shotcrete and reinforced mesh

The obtained test results are shown in Table 5.

Table 5 –Test results for shotcrete slabs at the age of 28 days

Mix mark	*Results of testings slabs*		
	Maximal load	*Deflection*	*Absorption Energy at max load*
	kN	*mm*	*Nmm*
SC1-0kg (Slab)	*54,32*	*2*	*16963*
SC2-6 kg(Slab - PFfiber)	*72,685*	*25*	*86336*
SC3-35kg (Slab - SFfiber)	*45,331*	*25*	*115724*
SC4-Q(Slab – Q 524)	*119,815*	*25*	*434811*

4. CONCLUSION

At the impact of the punching force on the plates without fibers and constructive reinforcing mesh, the maximum force of 54,32 kN, the maximum deformation of 2 mm and the absorption energy of 16963 Nmm, have been achieved Polyolefin reinforced polymer slabs achieved a maximum punching force of 72,685 kN, the largest deformation of 25 mm, and the absorption energy of 86336 Nmm. Steel reinforced slabs achieved a maximum force of 45,331 kN, the greatest deformation was 25 mm and the absorption energy 115724 J. The obtained value of the force in breaking the steel fiber reinforced slabs is unexpected. This value was obtained due to the uneven fiber distribution during the mixing of concrete. Shotcrete slabs with constructive reinforcing mesh had the highest values of the slab punching. The force of 119,815 kN, with the maximum deformation of 25 mm and the absorption energy of 434811 Nmm was obtained.

On the basis of the obtained values we can conclude that it is possible to use shotcrete reinforced with fibers. Shotcrete with synthetic (polyphylene) fibers showed better mechanical punching properties, as well as preservation of the integrity of the slabs after reaching the highest load in relation to the steel fiber slabs.

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УТИЦАЈ ВРСТЕ АРМАТУРЕ НА СВОЈСТВА МЛАЗНОМ БЕТОНА КОД ПРИМАРНИХ ОБЛОГА ТУНЕЛА

Резиме: *У овом раду је приказана могућност примене полиолефинских и челичних влакана у млазном бетону који би се користио у тенелима при изради примарних облога. У експерименталном раду су направљене плоче од млазног бетона без и са садржајем полиолефинских и челичних влакана, као и плоче са конструктивном арматурном мрежом. Плоче од млазног бетона су испитиване на пробијање (енергија абсорпције). На основу резултата испитивања претпоставља се да је могућа примена влакана у млазном бетону приликом израде примарне облоге тунела. Добијене вредности испитивања млазног бетона са садржајем полиолефинских влакана, постигнута су повољна механичка својства.*

Кључне речи: *млазни бетон, ојачање влакнима, енергетска апсорпција*