Fiber reinforced shotcrete - the benefits of the application in tunnel building

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Abstract : Fibers enhance the psysical and mechanical properties of concrete and bring wider application of such composite in real projects. The technological development of equipment for the installation of concrete by spraying enabled the use of micro-reinforced concrete, primarily in constructive systems for ensuring the excavation of underground structures. The paper will present the results of testing physical and mechanical properties of concrete mixtures with steel fibers. The adventages of using such a composite on lining of underground structures will be specified. Recommendations for making and installation of micro-reinforced concrete with spraying technology, as well as the approach to dimensioning the tunnel lining made of micro-reinforced concrete will be presented.

Key words: fiber, concrete, physical-mechanical properties, spraying technologies

Mikroarmirani mlazni beton - prednosti primjene u tunelogradnji

Sažetak: Poboljšavanjem fizičko-mehaničkih svojstava betona, dodatkom vlakana, obezbjeđuje se sve šira primjena takvog kompozita, u realnim projektima . Tehnološki razvoj opreme za ugradnju betona prskanjem, omogućio je upotrebu mikroarmiranog betona, u prvom redu u konstruktivnim sistemima osiguranja iskopa podzemnih konstrukcija. U radu će se prikazati rezultati ispitivanja fizičko-mehaničkih svojstava betonskih mješavina sa čeličnim vlaknima. Specificirati će se prednosti primjene ovakvog kompozita u izradi obloga podzemnih konstrukcija. Prikazati će se preporuke za spravljanje i ugrađivanje mikroarmiranog betona tehnologijom prskanja, kao i pristup u dimenzionisanju tunelske obloge od mikroarmiranog betona.

Ključne riječi: vlakno, beton, fizičko-mehanička svojstva, tehnologija prskanja

1. INDRODUCTION

The possibility of installing micro-reinforced concrete with spraying technology gives great advantages to this material in ensuring excavation in tunnel construction. The addition of fibers to the concrete matrix greatly improves the physico-mechanical properties of the same, and as a composite it finds increasing application in the elements of constructions carried out by the classical technology of concrete installation. The basic composition of micro-reinforced concrete is similar to ordinary concrete. For similar purposes, apart from adding fibers , micro-reinforced concrete differs from ordinary concrete by increased amount of cement, lower incidence of large aggregate and smaller size of maximum grain of aggregate. Also,additives for improving the workability of fresh concrete, as well as additives for increasing the adhesion of fibers and matrice of mortarare almost always applied.

1.1. Types of fibers and their contribution to the properties of concrete

From the first applications to date, natural organic fibers, fibers made of glass or alkali resistant glass, mineral fibers, carbon fibers, polypropylene fibers and various other synthetic fibers are in use. The length of the fibers is usually from 5 to 75 millimeters. The fibers can be successfully mixed with conventional technology in a concrete mixture up to two percent by volume of thick fibers, and if the fibers are thinner, then up to several promises.The main contribution of micro-reinforcement is in the post-cracked state, because the fibers bridge the cracks and contribute to increasing the strength, deformation and toughness of the composite. The influence of fibers on the improvement of micro-reinforced concrete properties begins in the phase of stable crack propagation (up to 70% of the concrete strength), and it continues in the process of unstable crack propagation.

The ability of the composite to withstand a large deformation, after a crack and before failure, is often measured by the toughness index. The grade of toughness depends on the type and geometry of the fibers, the amount of fibers, the composition of the concrete mixture, the size of the test body, the configuration and the load speed, the accuracy of the deformation measurement, the rigidity of the test apparatus compared to the rigidity of the tested test body. Micro-reinforced concrete is often designed to require a certain compressive strength as well as the type and amount of fiber. In some special cases, the required parameter is the toughness index. The strength test on the pressure of micro-reinforced concrete makes sense only as a simple test for checking the uniformity of the quality of hardened concrete. However, for estimating the contribution of fibers in concrete the overall working diagram is crucial and it is obtained by testing the bending prism. The contribution is then estimated by comparing the work diagrams or derived quantities such as toughness indexes and other parameters..

2. MIXTURES OF MICRO-REINFORCED CONCRETE

Special attention should be paid to the mixture of micro-reinforced concrete. It should be pointed out that the maximum grain size of the aggregate is interdependent with the length of the fiber, which affects the workability of the classically mixed mixture. The maximum grain aggregate should be between one third and a half of the length of the fiber. The maximum grain aggregate should be between one third and a half of the length of the fiber. It should be noted that the presence of a larger amount of smaller fractions causes increased concreting of the concrete during drying, while the increased quantity of the larger fraction causes a higher bounce. Micro-reinforced shotcrete is installed with the same equipment as ordinary sprayed concrete, wet or dry. However, usually, there is a problem of uniform fiber dosing in the applied mixture. The problem is created by increasing the amount of fiber, as well as by increasing the factor of fiber shape. In these situations, accumulation of fibers and smaller fractions of the mixture occurs, creating "hedgehogs", which significantly impairs the process of installation and reduces the quality of the projected mixture. For these reasons it is necessary to do the dosing of the fibers on nozzle itself, regardless of the installation technology applied. In Figure 1, a number of recommendations are presented schematically, which should be observed when installing shotcrete.

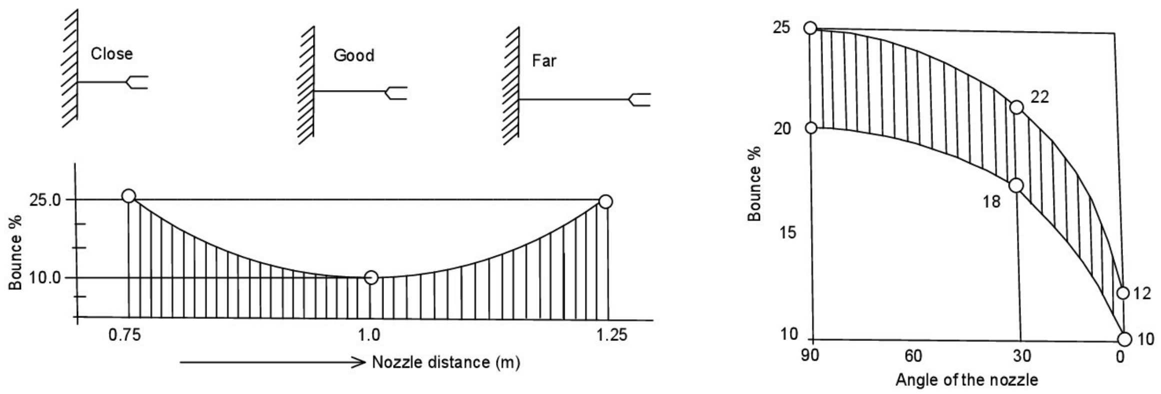

Figure 1. Bounce of the material in function of angle and distance of nozzle

The idea that these fibers, inorganic or organic, are added to the fresh matrix of concrete, has been designed to improve some of their engineering properties in a relatively simple way: toughness, fatigue resistance, impact strength, bending strength and much more. Properties are not improved if amount of fiber increase, but certain optimization of concrete mixture properties mixture and fiber is required. During mixing, it is necessary to prevent the segregation and clotting of fibers, and these processes depend on a number of factors. One of the most important is factor of fiber shape. If the factor of fiber shape (ratio of length and diameter of fibers) is greater than 100, the difficulty in mixing increases, but there is the contribution of such fibers to more favorable properties of micro-reinforced concrete. Once when fiber bundles are formed, it is very difficult to separate fibers in the further process of mixing. The choice of fiber thickness is also conditioned by the maximum possible number of fibers in which there is no accumulation in the "hedgehogs". The expression for calculating the maximum mass of fibers that can be mixed in concrete with a maximum grain aggregate of 16 mm was obtained experimentally and reads:

$$M = 0{,}74 \times \rho \times \frac{d}{l} \qquad (1),$$

where M is the mass of the fibers in kg / m3 of concrete, ρ is the fiber density in kg / m3, and d / l is the reciprocal value of the factor of fiber shape.

2.1. Composes of the mixtures in function of the lenght and dose of the fiber

Table 1- Composes for one m^{3}of the mixture with strengths determined after 28 days

SERIES	FIBER			AGGREGATE			CEMENT	ADDITIONS (kg)		STRENGHT (Mpa)				Modu-lus of elastic-ity (GPa)
	L	D	Mass	0-4	4-8	8-16		Super-plastifikator P	Micro silica	Pressure	Tension		Shearing	
	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	kg				By Cleaving	By bending		
I/A	-	-	-	957	192	766	400	6	-	59.03	3.97	4.22	9.08	38.30
I/B	16	0.5	80	943	188	755	400	6	-	65.04	4.98	5.14	14.18	41.06
I/C	16	0.5	120	923	184	738	400	6	-	68.10	5.75	5.87	15.14	41.25
I/D	16	0.5	160	903	180	722	400	6	-	71.71	6.24	7.46	14.03	45.24
I/E	32	0.5	80	943	188	755	400	6	-	69.48	5.17	6.42	14.50	41.06
I/F	32	0.5	120	923	184	738	400	6	-	71.82	6.08	8.00	15.97	41.16
I/G	32	0.5	160	903	180	722	400	6	-	67.78	7.87	8.81	18.40	40.17
I/H	64	0.5	48	945	189	756	400	6	-	65.59	5.61	5.13	13.54	39.43
I/I	64	0.5	80	943	188	755	400	6	-	60.59	5.14	5.97	16.09	36.02
I/J	64	0.5	120	923	184	738	400	6	-	59.36	5.07	8.38	15.44	33.15
II/A	-	-	-	1010	367.5	459.5	378	-	42	27.90	3.20	-	-	-
II/B	32	0.5	40	976.5	355	443.5	378	-	42	26.20	4.80	6.25	-	-
II/C	32	0.5	60	1017	357	462	378	-	42	31.00	5.20	16.67	-	-
II/D	32	0.5	80	973	353.5	442.5	378	-	42	32.30	5.40	31.25	-	-

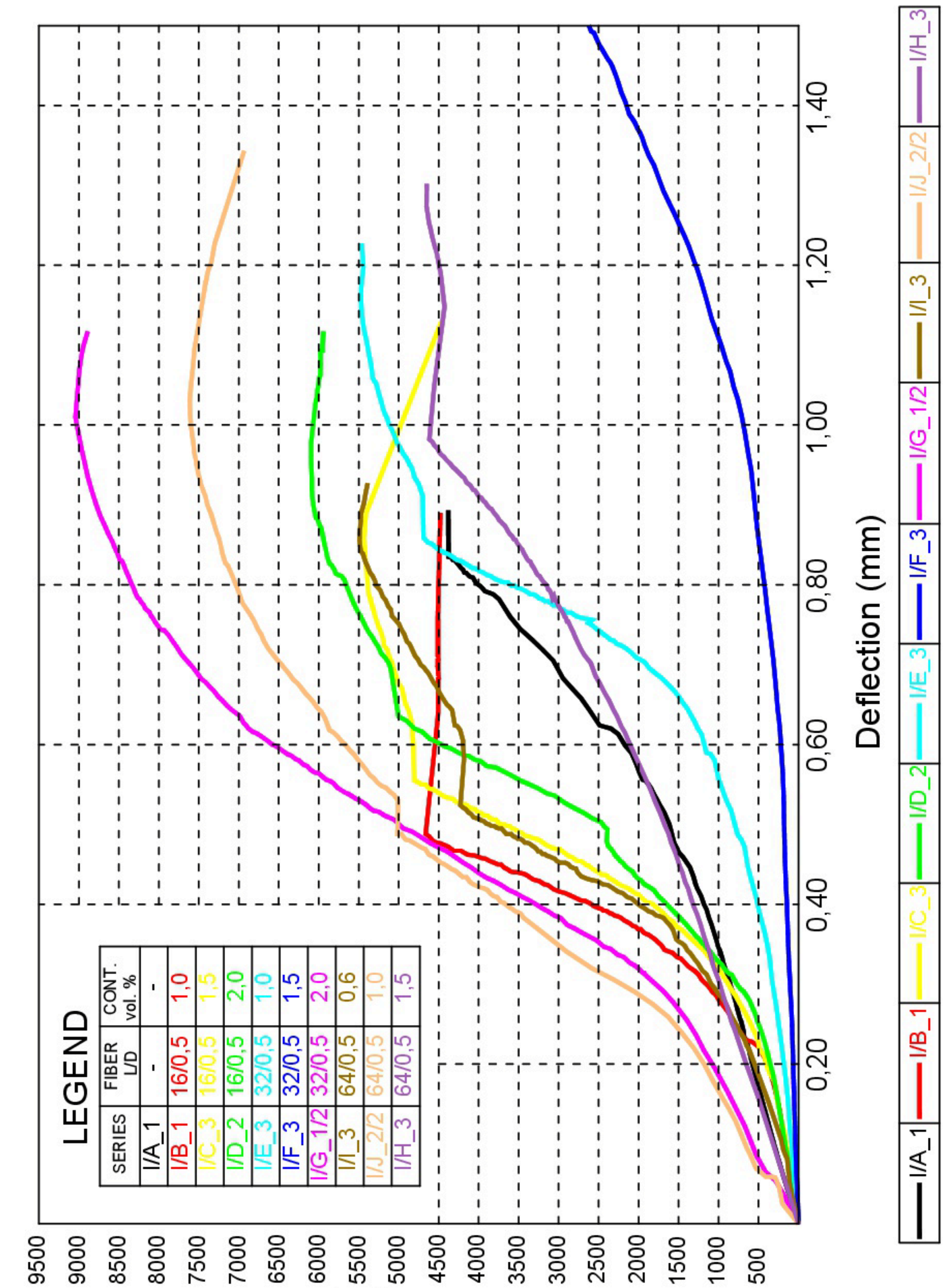

Figure 2. Working diagrams of series for bending MR concrete in function of length and dose of the fiber

The fibers that are shown in Figure 3 were used to prepare the mixtures of micro-reinforced concrete. The fibers are 0.5 mm in diameter and have different lengths (16 mm, 32 mm and 64 mm).

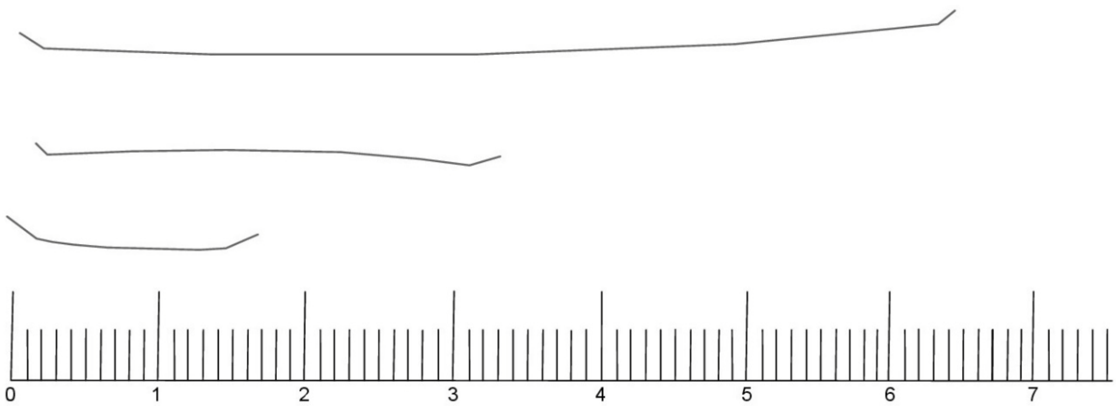

Figure 3. Fibers that were used in mixtures

Characteristics of applied steel fibers are:

- maximum tensile strength: Rm=841 MPa
- elasticity limit : Re=805 MPa
- interrupted deformation : Δ=0,4%
- modulus of elasticity: E=2,025·105 Mpa

Table 1 contains mixtures of micro-reinforced concrete installed conventionally (series I/A-I/J) and shotcrete (Series II / A-II / D series). In the same table, the strengths of micro-reinforced concrete after 28 days are shown, and strengths are on: pressure, tensile (splitting, bending), shear, as well as static modulus of elasticity. It is evident from the table that all the strengths of the micro-reinforced concrete are increased in relation to the fiber-free concrete matrix. Figure 2 shows bending working diagrams for the micro-reinforced concrete series I/A to I/J. Micro-reinforced concrete does not lose capacity with appearance of first cracks in the concrete matrices under load. Depending on the correct mixture composition, with increasing load, existing crack will progressively expand, or if there is greater presence of fibers that bind crack, new cracks will form. With load increse, this process will lead to the connection of cracks with the slightest resistance across the cross-section of the element. Sometimes, after the appearance of the first crack, the stress does not increase, but deformation increases considerably, at the expense of the deformation of the fibers that overcome the cracking or their withdrawal from the matrice of the concrete. In both cases there is significant increase of toughness of micro-reinforced concrete compared to classic concrete (without fibers).This characteristic is of great importance during building the primary lining in tunnel excavations.By installing micro-reinforced concrete by spraying, the fibers are mainly distributed in the perpendicular surface in relation of spraying. The ability to install micro-reinforced concrete during tunnelworks by spraying, contributed to the realization of tunnel lining, and thus to the reduction of total tunnel cost.In primary tunnel lining made of sprayed concrete, the fibers almost completely replaced the reinforcing steel meshes.

2.2. The advantages of micro-reinforced concrete and calculation of required lining

Compared to concrete reinforced with steel meshes, micro-reinforced concrete has following adventages:

- lower workload and faster workflow,
- less material consumption, because the configuration of the excavation is followed better, which is not the case with classically reinforced sprayed concrete, where the net does not always come in the tensile zone,
- fiber increases the homogeneity, tensile and shearing strength of the concrete composite,
- fibers reduce the occurrence of microprocesses,
- micro-reinforced spraying concrete is more resistant to abrasion, corrosion and impacts,
- Safer working conditions, avoiding meshes installation and anchoring in the tunnel zone where deformation is not complete,
- the advantage is organizing works in a limited space.

Calculation of the required lining of micro-reinforced concrete can be done by applying an inverse procedure, using the reactive load of the supported structure in the analysis of the boundary states.Namely, it is difficult to determine the boundary impact of the rock mass on the supported structure, but it is possibleto define the pressure on which the support structure acts on the rock, knowing characteristics of the material and the geometry support structure.Beside the permitted (broder) reaction of the support structure, the rock should also satisfy the fracture criteria.This would demonstrate the possible boundary equilibrium of the support-rock system with the necessary factor of safety for the support structure and satisfing the criteria for the fracture of the rock.In this way, under such conditions, the influence of the boundary condition of the support structure on the rock would be directly applied.The loading of the rock by boundary interaction of support structure and rock can be determined, and it si used as input data in the analysis of the stress state and deformation of the rock around tunnel hole.By comparing the stresses obtained around excavation hole with the criteria of the fracture, the measure of the safety of the rock-support system is obtained.

3. CONCLUSION

Due to its physical and mechanical properties, micro-reinforced sprayed concrete is increasingly becoming basic element of support structure systems of underground excavation, marked as primary lining.Enhance toughness and strength in bending of micro-reinforced concrete ensures significant bearing capacity of lining even after cracking, and great deformations must precede the separation of concrete and rock. Such behavior is particularly appropriate in tunnels and mines, where largesubsequent rock deformations are possible.During the spray application, the fibers are orientated (mostly) in the perpendicular surfaces in relation of nozzle direction (2D distribution), which improves the bending strength of the lining. Knowing physical - mechanical properties of micro-reinforced concrete,it is possible to define thickness of the lining with "inverse procedure ", by satisfyling the fracture criteria of the rock mass. To achieve the required physical and mechanical properties of the micro-reinforced concrete, it is necessary to optimize the composition of such a mixture.This applies in particular to the amount of fiber supplied and the granulometric composition of the aggregates.

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