REVEW OF CERTAIN APPLICATIONS OF FIBRE REINFORCED CONCRETE IN SLOVENIA

ŠUŠTERŠIČ Jakob [1], ZAJC Andrej [2]

Abstract

In the paper, review of certain applications of fibre reinforced concrete in Slovenia are shown and discussed. Those applications are results of many research and development projects of our Institute. Four of them (pre-stressed concrete sleeper made from SFRC, high performance kerbs, thin pre-stressed slabs and underwater abrasion resistance concrete linings) are shown, briefly. Development of roadway support panels with traditional reinforcement and fibre reinforcement is shown and discussed more in detail. . Because of crack propagation in length direction as well in width direction is prevented by presence of fibres in concrete, fibres keep the strength from falling after first crack. This is one of the fundamental functions of fibres in concrete. Bond between concrete and steel bars is increased as well, by bridging effect of fibres. Improvement in bearing capacity of the panels with traditional steel reinforcement and fibre reinforcement is evident from their performance, when they are installed in the mine roadway support under geomechanically poor conditions.

Keywords: fibre reinforced concrete, high performance concrete, steel fibres, polypropylene fibres, toughness

1. Introduction

In our practice, fibre reinforced concretes (FRC) with different mode of mix - proportions and with different types and combinations of fibres have been used. Brief descriptions of four applications are given in the second chapter. In the third chapter, results of initial investigations of roadway support panels with traditional reinforcement and fibre reinforcement are shown and discussed.

FRC are widely used for slab constructions in our practice, likewise as all over the world. Our Institute introduced some new ideas in this field [14, 16, 17]. Some effective applications were made with fibre reinforced shotcrete for construction of linings in mine and tunnels as well [15,18 - 21]. Several years old use of bridge deck overlays made from HP FRC shows that those overlays would be use as a waterproofing-abrasive bridge deck layers [22]. Different types of HP FRC mixtures have been used which show following

[1] ŠUŠTERŠIČ Jakob, IRMA Institute for Research in Materials and Applications, Slovenčeva 95, 1000 Ljubljana, Slovenia, jakob.sustersic@irma.si

[2] ZAJC Andrej, IRMA Institute for Research in Materials and Applications, Slovenčeva 95, 1000 Ljubljana, Slovenia, andrej.zajc@irma.si

characteristics: ductile behaviour, in spite of high strengths, high level of permeability to water and abrasion resistance and freeze – thaw resistance with de-icing salts.

2. Brief descriptions of four applications

2.1 Pre-stressed concrete sleeper made from SFRC

Pre-stressed Concrete Sleeper made from Steel Fibre Reinforced Concrete (PCS-SFRC) has been developed in the frame of research and development project financed by Ministry of Higher Education, Science and Technology and Slovenian Railways [1]. The test results of new developed sleeper showed that it has substantial improved mechanical properties in comparison with the pre-stressed concrete sleepers made from concrete without fibers. Diagram in Figure 1 shows behavior of PCS-SFRC during the three point bending test.

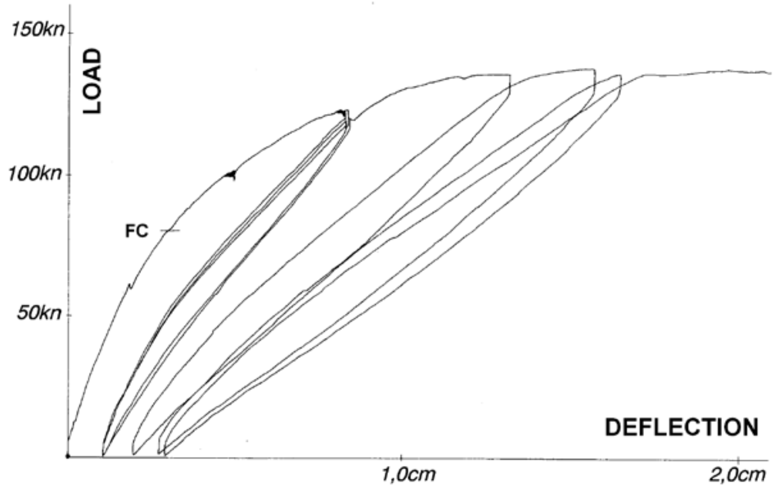


Fig. 1: Characteristic load – deflection diagram of pre-stressed concrete sleeper made from SFRC.

Because of its mechanical properties are direct connected with mix proportion of the SFRC, used for its production, there is possible to arrange mechanical properties of sleepers in regard to requirements. It means, that many types of sleepers should be produced in regard to conditions on the railways in which those sleepers should be placed. Because of the polygonal placed pre-stressing tendons and the shape of reclined surface of the sleeper there was also developed a special device which enables the simultaneous vibrating of SFRC, pre-stressing of tendons and shaping of the reclined surface. Working of the device has been tested by the pilot production of 1000 sleepers (Figure 2), which were placed in the railway segment and monitored through inserted measuring cells placed in some of these sleepers. After 20 years of exploitation, there are no failures on the sleepers.

2.2 High performance kerbs

High performance kerbs are produced using the double-layer press technology (Figure 3) [2]. The primary bearing layer, which must resist all impact loads, is made from SFRC. The secondary – wearing layer, which must not only have increased resistance against wear but also a corresponding resistance against the aggression of thawing salts and against freezing, is made by latex-modified concrete (LMC).

Fig. 2: Pilot production of PCS-SFRC.

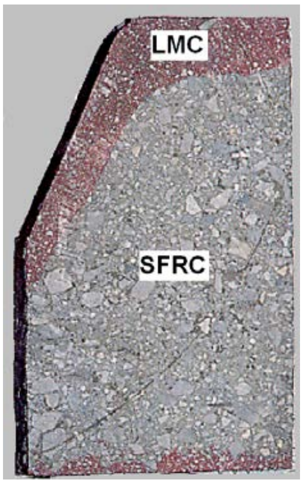


Fig. 3: Cross section of high performance kerb.

2.3 Thin pre-stressed slabs

Thin (4 cm) pre-stressed slabs made from SFRC has been used as a lost paneling during the construction of the arched bridges [3]. This patented system is based on previously manufactured thin pre-stressed slabs prefabricated in the factory on a flat surface, and after 24 to 48 hours bent into the shape of the planned arch of the lower contour of the bridge (Figure 4).

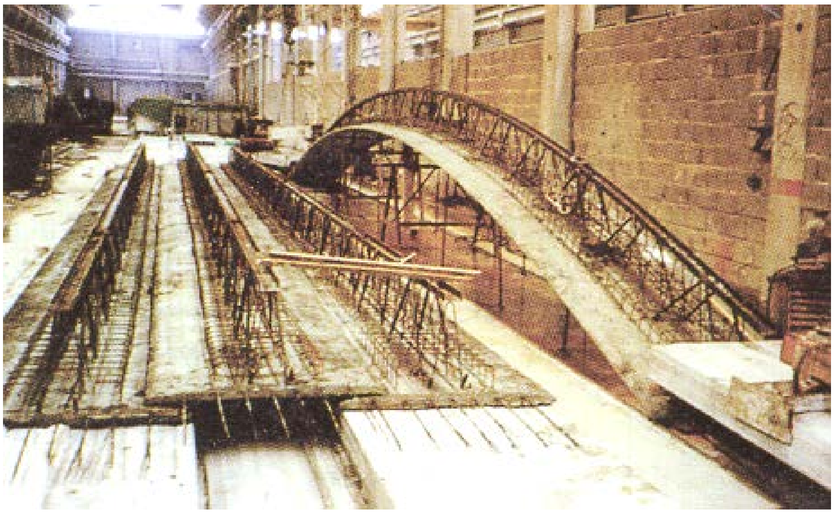


Fig. 4: Flat and shaped thin pre-stressed slabs in production.

Such a procedure, which besides the already existing pre-stressed forces in the concrete causes additional high tensions, can be carried out only with the use of high performance SFRC. Its properties allowed for a relatively simple procedure for arching the young concrete without the appearance of cracks or wrong shapes. Four such manufactured elements were placed using a pulley system onto the prepared foundations of the bridge, representing scaffolding for further progress in the construction of the arch.

A very convenient system, used in the case of 40 m Soča bridge near Doblar in Slovenia, utilizes transverse placements of extruded hole concrete slabs spanning a Vierendel bearing system after emplacement of the first concrete between them (Figure 5 (a)). In the later stages of constructions, the arch was incorporated into the main bearing arch system of the bridge (Figure 5 (b)).

(a)

(b)

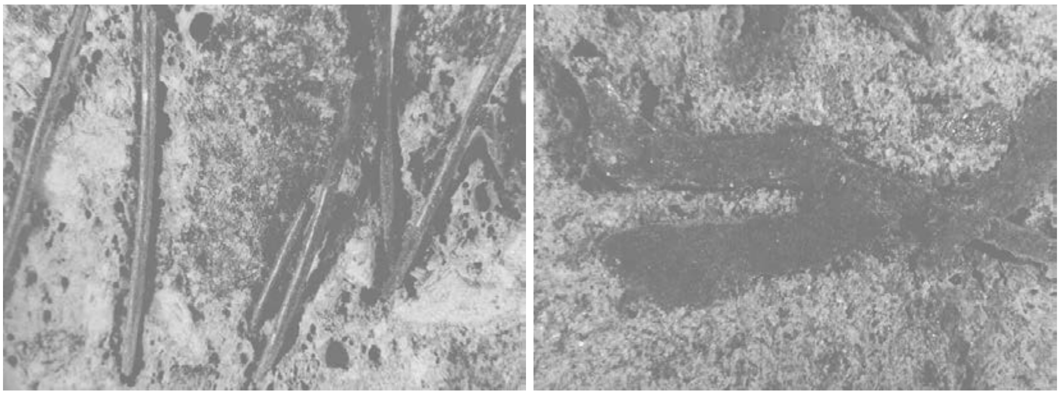
Fig. 5: (a) Soča bridge after placements of whole concrete slabs and the first concrete between them; (b) finished arch bridge.

2.4 Underwater abrasion resistance concrete linings

SFRC is used for construction of underwater abrasion resistance concrete linings of the stilling basins of the downstream hydro power plants on the Sava river in Slovenia [4]. The chain of the hydro power plants on the Lower Sava River consists of 6 run-of-river plants. Vrhovo power plant as the first in the chain has been in operation since 1996, the second one, Boštanj power plant operates ten years already, the third one, Blanca power plant sixt years, fourt one, Krško power plant two years, and the fifth one, Brežice power plant is at the construction.

Steel fibers have an important abrasion resistance effect of concrete [4, 5]. With the use of FRC the following parameters must be taken into account: composition of concrete; bonding ability between fibers and hardened cement paste; hardness of steel fibers. When FRC is initially exposed to abrasion forces, only a thin top layer of surface mortar resists these effects. After this top layer is depleted, the fibers become exposed. If these fibers are made of hard steel, water flow and movement of solid water borne particles causes vibration of the exposed fibers (Figure 6 (a)) [6]. When the fiber vibrates, it creates intense stresses, resulting in concentration of stresses. These stresses furthermore cause deterioration of concrete which in turn results in extrication of fibers from the concrete.

Fibers made from softer type of steel are flattened out while exposed to water flow containing abrasive particles. At the same time, they are not extracted when an acceptable bonding quality is achieved between fibers and mortar (Figure 6 (b)) [6]. Hardness of steel fibers was approximately 250 HB. From the picture in Figure 6 (b) it is evident that the steel fibers were flattened out to the extent which is approximately 5 times wider than their diameter prior to action of abrasion load. In this manner a good safeguard is achieved which prevents further deterioration of the concrete.



(a) (b)

Fig. 7: Surfaces of fiber reinforced concrete with: (a) hard steel fibers (approximately 550 HB) and (b) with soft steel fibers (approximately 250 HB) in vicinity of fibers after exposure to abrasion forces [6].

3. High performance mine roadway support panels with traditional steel and fibre reinforcement

3.1 Introduction

The Velenje Lignite Mines includes permanent sites and sites that are needed only temporarily. The more permanent sites must be constructed with a substructure that has the necessary load-bearing capacity for specific geomechanical conditions. All concrete substructures fall under this category of substructure. In the past, substructures were mainly constructed from concrete molds, ordinary concrete linings in combination with steel anchors and concrete panels with traditional steel reinforcement. In recent years high performance concrete panels with traditional steel reinforcement and fiber reinforcement have chiefly been used.

Although concrete panels with traditional steel reinforcement are generally suitable for supporting mine works under all conditions, the existing procedures to date have shown that this is not exclusively so. Because of the influence of coal excavations in the direct vicinity of the constructed panel lining, damage has begun to appear at certain locations. This damage to the entire installed lining made from panels with traditional steel reinforcement have shown that the panels were at the limit of their load-bearing capacity or that their load-bearing capacity had already been exceeded, when they were used for the sub-structuring of rails under geo-mechanically poor conditions or in regions with large rock formation pressures. Solutions are being looked intensively for the necessary repairs to the damages sections of the rail lining.

The following presuppositions or criteria were placed for finding solutions:

- repairs are to be carried out with assembly elements – panels,
- the transverse-section of railway is to remain the same,
- the existing technology and equipment are to be used for installation.

On the basis of the existing knowledge about the properties of steel fiber reinforced concrete , a project was carried out with the above-mentioned criteria, and with the goal of improving and increasing the performance and bearing-capacity of the panels without increasing their price with regard to current concrete panels with traditional steel reinforcement.

There are two reasons to use fiber reinforced concrete for production of structural elements [7]:

- fibers increase a tensions strength of concrete so that all tension stresses or part of them are undertaken by concrete in an element; therefore an appointed part of reinforcement or all of it can be replaced by fibers; at the same time, some other properties of concrete element are improved too; with that, higher economical effect can be expected;
- fiber improve some foreseen behavior of an element, it's safety is secured by designing according to known method, by reinforced bars; because of adding fibers, the cost of product become higher; it can be justifiable regard to improvements of quality (higher ductility, arrest of crack propagation, improvement of durability, etc.).

There are no enough experiences of long duration with designing fiber reinforced concrete structural elements and there are no parameters and criterions in the technical regulations. But, there are already some recommendations for calculations of concrete element dimensions and quantity of both reinforcements – traditional (steel bars, meshes, stirrups) and fiber (steel) [8 – 11]. However, the behavior of the elements can be predicted only on the base of experimental results. Behavior of the mine roadway support panels with different types of reinforcement has been observed by experiments. The results and statements of the experiments are shown and discussed in the next items.

3.2 Experimental details

For the development project it was decided that new panels should have the same shape and dimensions as the existing ones. The dimensions of the panels are as follows: r_{inside} = 190 cm, thickness = 16 cm, width = 49,5 cm, inside length = 298,5 cm. Three types of panels of the same shape and size were manufactured and tested (three of each type), they differed only in regard to the manner of reinforcement and concrete composition (Table 1).

Tab. 1: Tested panel types.

type of panel	D_{max} (mm)	steel fibres (vol.%)	Traditional reinforcement	
			Bars	Stirrups
A	32	0	2 × 3∅12 mm	∅6 mm/15cm
B	16	0,5	-	-
C	16	0,5	2 × 3∅8 mm	∅6 mm/50cm

The method of testing panels is shown in Figure 8. Deformations at various locations of the panel and the bending at the center were measured in accordance with the loading during the tests. In both mix proportions, following materials are used: Portland cement CEM I, crushed dolomite aggregate and superplasticizer. Hooked steel fibres with length of 32 mm and with aspect ratio of 100 and silica fume are added only in the SFRC mixture (see Table 2 where both mix proportions are summarised).

Tab. 2: Mix proportions (per 1 m^3 of concrete)

parameter			concrete without fibers (for panels A)	SFRC (for panels B and C)
cement (C)		kg	420	420
w/b ratio		-	0,36	0,41
silica fume		mas.% of C	-	10,0
steel fibers		vol.%	-	0,5
superplasticizer		mas.% of C	1,5	1,5
fractions of aggregate (mm)	0-4	vol.%	26	42
	4-8	vol.%	10	10
	8-16	vol.%	19	48
	16-32	vol.%	45	-

3.3 Results and their discussion

3.3.1 Test results of fresh and hardened concrete

The results of testing fresh and hardened concrete without fibers and SFRC are given in the Table 3. The age of hardened concrete is 28 days. Each discussed result is the average of the results obtained from the tests of at least three specimens.

Tab. 3: Average values of obtained results of fresh and hardened concrete without fibers and SFRC.

properties of fresh and hardened concrete		concrete without fibers (for panels A)	SFRC (for panels B and C)
slump	cm	1,0	1,0
w/b ratio	-	0,42	0,44
pore content	vol.%	1,2	1,6
density of fresh concrete	kg/m^3	2473	2457
compressive strength	MPa	64,9	68,0
flexural strength at first crack	MPa	6,2	7,4
toughness index I_{10}	-	1,0	8,5
impact toughness	kJ/m^2	-	30,5

While the properties of fresh concrete with and without fibers do not essentially differ, the differences in hardened concrete are greater. The concrete differ above all with respect to flexural strength and toughness, where these values of SFRC results are quite larger. The diagrams from Figure 8 show, that the load carrying capacity of cracked concrete without fibers falls very quickly. Whereas, the load carrying capacity of SFRC reached its ultimate value in the beginning of crack propagation.

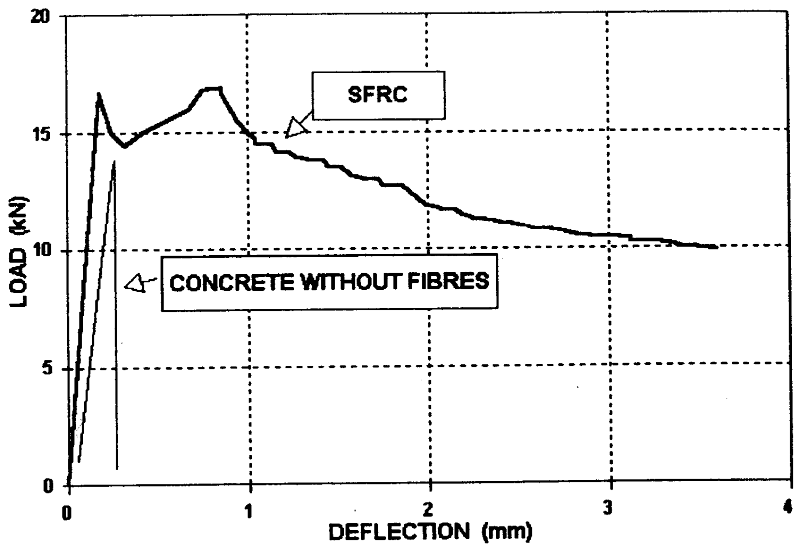


Fig. 8: Characteristic load – deflection diagrams of SFRC and concrete without fibers.

A static third-point bending configuration was used for toughness measurements in accordance with ASTM C 1018. The measurements were carried out on concrete beams, which had nominal cross section of 100 × 100 mm and were 400 mm long. The span length was 300 mm. Compressive strength were measured on the cubes with edge length of 15 cm. Impact toughness was measured by Charpy's impact hammer. Prismatic specimens (4 × 4 × 16 cm), placed on two supports and notched on one side, were hit by the test hammer. Toughness is defined as the work per unit of cross-sectional area which is needed to break the prism.

3.3.2 Test results of fresh and hardened concrete

In the testing of Type A panels a shear break occurred relatively quickly at the site of support (panel joint). These permanent deformations are identical to the permanent deformations appearing in the damage of panels in mine railways.

In Type B panels (with steel fibres and without reinforcement), the maximum load, which was approximately 40 % higher than that of Type A panels, made a break in the panel which appeared in the vicinity of the action of the outside load (in the center).

In Type C panels a very large deformation occurred at nearly the same maximum load but the panel did not break. Only after repeated point loading at the center could the panel be broken at the quarters and in the center. Here the reinforced bars also snapped. Before snapping a transverse contraction of the rods occurred.

Cracks were measured on the both lateral sides (cracks were occurred on the lower part and in the middle area with length of 50 cm approximately) and on the upper area of panel (cracks were occurred on the two areas of one fourth of upper panel arc: 20 cm to 70 cm from left and right border approximately). These areas are shown in Figure 9.

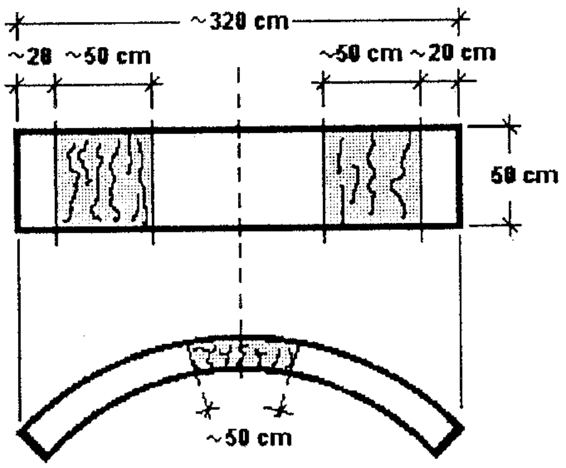


Fig. 9: Areas of cracks propagation on panel.

Obtained joint lengths of cracks in accordance with load are given in Figure 10 (cracks of upper part separate from cracks of lower part of panel) and in Figure 11 (all obtained cracks of the panel type together).

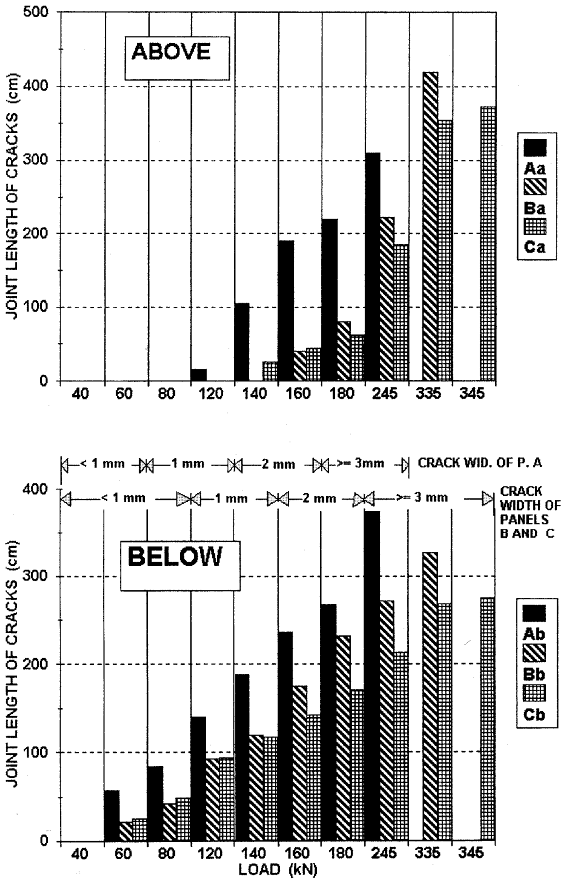


Fig. 10: Correlation between load and joint length of cracks on the upper and lower parts of panels.

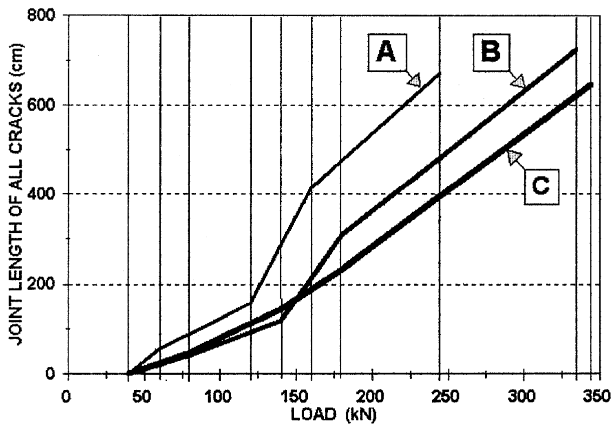


Fig. 11: Correlation between load and joint length of all cracks on panel.

The greatest joint length of cracks is obtained on the panel A (concrete without fibers). Lower part of panel C has only half of it approximately at the ultimate load of panels A (245 kN). Joint length of all cracks of panel C is 60 % approximately less than same length of panel A

Cracks began to propagate at the same time and at the load of 40 kN approximately on the lower and middle area of all panels. However, cracks of upper areas of panel began to propagate much later: at first on the panel A (at the load of 80 kN), then on the panel C (at 120 kN) and at the end on the panel B (at 140 kN). Obtained crack widths are divided in four categories:

- width of cracks less than 1 mm,
- width of cracks 1 mm approximately,
- width of cracks 2 mm approximately, and
- width of cracks greater or equal 3 mm.

Cracks, with width less than 1 mm, were appeared on the panels A in the span of load from 40 to 80 kN. Then, the crack widths were increased in the equal spans of load approximately (≈ 60 kN). Joint lengths of all cracks on panels A, B and C with equal width are shown in Figure 12 up to ultimate load of panel A (245 kN).

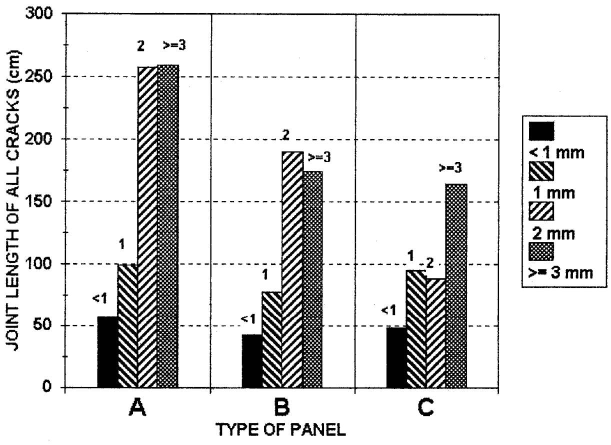


Fig. 12: Interdependence of joint length of all cracks on panel and their width.

These lengths are decreased very much by an increasing of crack width on the panels with SFRC in relation to panel A (panel with concrete without fibres).

Joint crack lengths on panel B and C are increased (on panel B for 242 cm and on panel C for 252 cm) by an increasing of load beyond 245 kN up to their ultimate loads (335 and 345 kN respectively).

Effect of fibres is evident too from results of measuring number, mutual distance and length of single cracks on equal areas approximately (≈ 50 cm) in the middle of panel bellow and on the two areas of one fourth of upper panel arch (Figure 9). The number of cracks on panels B and C is higher and their mutual distance is smaller in regard with those of panel A. However, the crack lengths of panel B and C are smaller (Figure 13).

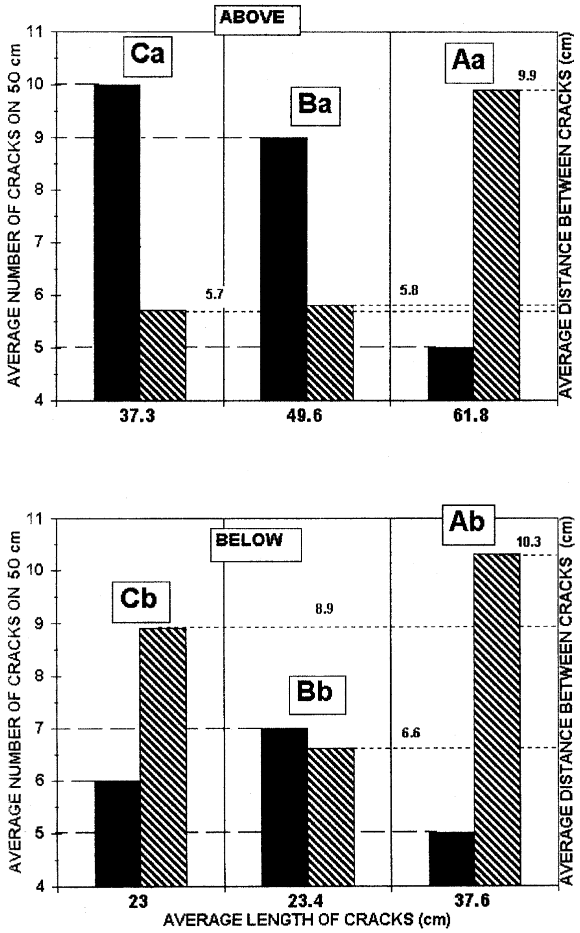


Fig. 13: Correlation between average number and mutual distance of cracks and average length of single crack on the equal area approximately (≈ 50 cm) in the middle bellow (A_b, B_b, C_b) and on the two areas of one fourth of upper panel arch (A_a, B_a, C_a).

3.4 Further development of the panels

By carrying out the given development project and reviewing all the received results it was ascertained that the damaged sections of the railway lines made from panels with traditional reinforcement can be replaced by the high performance panels with traditional steel and fiber reinforcement. The same equipment as in basic railway construction was used for repairs.

The results of the tests of the panels with traditional and fiber reinforcement brought us to the conclusion that the panels should be produced with so-called male and female (M – F) sections for placing upon supports. With such panels we avoid the use of so-called H connectors used in constructing rings in level sections. This form of joint – the M-F joints – signifies a 7% saving on the price of the panel for the production of 1 m of rail.

Correct lying of male and female joints has to be done. If the laying should not be done correctly, the shear failure can be occurred. Improved laying of both joints and harmonized behavior of panels are obtain, if polymer modified mortar is used as it is shown in Figure

14. Those were obtained by laboratory investigations as well as in the testing field in the mine.

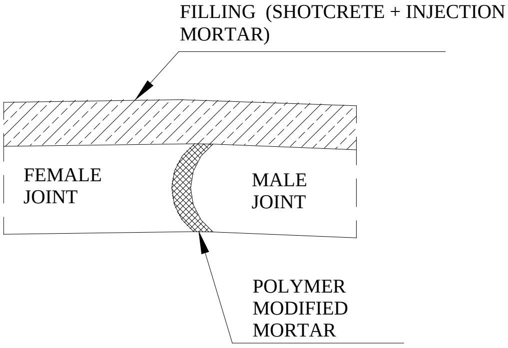


Fig. 14: Improved laying of male and female joints with polymer modified mortar.

In regions of the railway with large rock formation pressures, panels with traditional and fiber reinforcement with the higher load-bearing capacity and with the higher degree of ductility and toughness were developed (Figure 15). They are produced with high performance fiber reinforced concrete (HP-FRC) where steel and polypropylene fibers are used [12]. Steel and polypropylene fiber reinforced concrete (SPFRC) with higher ductility and toughness will be reached by modifications of their mixtures, if rock formation pressures in the main roadways should increase. Modification of SPFRC mixtures should be provided easy in the existing production. Use of HP-FRC with higher ductility behaviour in panels is depended on optimal solutions in regard to conditions in the mine.

Fig. 15: Panels with HP-FRC ready for installation in the lining of mine roadways.

New mechanical equipment, which was installed in Velenje mine, required enlargement of roadway cross-section so that inside diameter had to enlarge from 3,80 m up to 4,90 m [13]. Therefore, pressure behind the panel line becomes higher. When hydraulic pressure stage is taken into account in the calculation, the maximum pressure behind the panel line with initial diameter of 4.90 m is 32 % higher than that behind the panel line with initial diameter of 3,80 m.

Panels for support of the mine roadways with enlarged initial diameter of 4,90 m were chosen on the base of project analysis, results of calculations as well as results of laboratory investigations. Testing production and testing installation as well as behavior of new panels with traditional steel and fiber reinforcement in the testing field in the mine show that these panels are proper for the anticipative application. High performance fiber reinforced concrete is used in the production of those panels.

4. Conclusions

There are some general conclusions:

- FRC is useful composite materials, if it is use properly.
- If appointed content of fibres is simply added into concrete, moderate improvements of some properties (toughness, ductility, …) of FRC will be reached. More significant improvements (especially improved post crack behaviour) or effectiveness of fibres can be reached, if proper mix proportion is used.
- In the practice, use of FRC is evaluated from the economical point of view, too. The price of fibers has a significant influence on the decision of investor, and it can prevails over advantages given by the use of FRC. Therefore, FRC with low content of fibers is preferable, but in that case, effectiveness of fibers become very important.
- Because of lack of standard design methods, new FRC structural elements have to be tested before their applications to improve their bearing capacity.

Performance of installed panels with traditional steel and fiber reinforcement in Velenje mine roadway support under geomechanically poor conditions is quite good. The panels with high strength are ductile and tough enough to bear large rock formation pressures. Fiber reinforced concrete with higher ductility and toughness will be reached by modifications of their mixtures, if rock formation pressures in the main roadways should increase. Modification of FRC mixtures should be provided easy in the existing production.

Fiber reinforced concrete, used for production of panels, has high energy absorption capacity and high toughness respectively. Adding fibers prevent crack propagation in length direction as well in width direction. The fibers have very high influence on the shear behavior of the panels. Therefore, all stirrups in panel can be replaced by fibers. The stirrups are used only to tie up the reinforced bars.

References

[1] ŠUŠTERŠIČ J. Vorgespannte Eisenbahnschwellen aus Stahlfaserbeton. Zem. Beton (Vienna), vol. 37. 1995.

[2] KORLA J., Proc. of International ICPIC Workshop on Polymers in Concrete for Central Europe, Bled, Slovenia, 1996. pp 109-115.

[3] KORLA J., MAGAJNE D. Construction of arch bridges using prestressed SFRC elements as lost paneling. Concrete In The Service Of Mankind. Radical Concrete

Technology. Proceedings of the International Conference held at the University of Dundee. E & FN Spon. 1996. pp.221 – 230.

[4] ŠUŠTERŠIČ J., MALI E., URBANČIČ S. "Erosion-abrasion resistance of steel fiber reinforced concrete." Durability of concrete: second international conference. Montreal, 1991. Ed. V.M. Malhotra. ACI SP-126. pp. 729 – 743.

[5] ŠUŠTERŠIČ J. "Resistance of over 1-year-old SFRC exposed to long-term erosion-abrasion loading." Fiber Reinforced Cement and Concrete, Proceedings of the fourth RILEM International Symposium. Sheffield, 1992. Ed. R.N. Swammy. E&FN SPON. London. pp. 860 – 871.

[6] ŠUŠTERŠIČ J., KOMEL M., HUDEJ M., ZAJC A. "Underwater abrasion resistance of waterway tunnel concrete linings." Proceedings of the International Conference Composites in Construction – CCC2001. Ed.: J. Figueiras, L. Juvandes, R. Faria. A.A.Balkema Publishers. 2001. pp. 385 – 389.

[7] PAUL, S.L. Moment, Shear and Torsion, Design with Fiber Reinforced Concrete. Publication SCM-10 (85) ACI, 1985. Session 6, 1 – 2.

[8] RILEM TC162-TDF. Test and design method for steel fibre reinforced concrete: σ – ε design method. Materials and structures, 2000, Vol. 33, March, pp. 75 – 81.

[9] DUPONT D., VANDEWALLE L. Modelling SFRC with a stress-strain approach. Role of Concrete In Sustainable Development. Proceedings of the International Symposium dedicated to Professor Surendra Shah. September 2003, University of Dundee. pp. 103 – 112.

[10] Deutscher Beton – Vereih E.V. (1997a) Grundlagen zur Bemessung von Industriefuβböden aus Stahlfaserbeton. DBV – Merkblatt-Sammlung, Wiesbaden. 1997. (4.2). 16 pp.

[11] Deutscher Beton – Vereih E.V. (1997a) Bemessungs-grundlagen für Stahlfaserbeton im Tunnelbau. DBV – Merkblatt-Sammlung, Wiesbaden. 1997. (4.3). 23 pp.

[12] ŠUŠTERŠIČ J., KOLENC M., ZAJC A., BLAŽIČ A., RIČEK F., ZAJC-POGORELČNIK M. High-performance fiber reinforced concrete for mine roadway support panels. V: Malhotra, V. Mohan (ed.). High-performance concrete and performance and quality of concrete structures : proceedings, second CANMET/ACI international conference Gramado, RS, Brazil, 1999, (SP, 186). Michigan: ACI, 1999, pp. 101-111.

[13] ŠUŠTERŠIČ J., HUDEJ M., KOLENC M., ČIŽMEK D., BLAŽIČ A., ZAJC-POGORELČNIK M., ZAJC A. Development of new FRC panels for support of mine roadways with enlarged inside diameter. Ed.: Kostiov L. 5th International Symposium on Tunnel Construction and Underground Structures, Ljubljana, Slovenia, September 20-22, 2000. Proceedings. Ljubljana: University, 2000 , pp. IV-1-7.

[14] ŠUŠTERŠIČ J., ZAJC A., LESKOVAR I., DOBNIKAR V. Improvement in the crack opening resistance of FRC with low content of short fibres. Ed.: Dhir, Ravindra K. Role of concrete in sustainable development : proceedings of the International Symposium dedicated to professor Surendra Shah, Northwestern

University, USA held on 3-4 September 2003 at the University of Dundee, Scotland, UK. London: ″Thomas Telford″, 2003, pp. 167-174.

[15] ŠUŠTERŠIČ J., JOVIČIČ V., ZAJC A., ERCEGOVIČ R. Evaluation of Improvement in the Bearing Capacity of Fibre Reinforced Shotcrete Tunnel Lining. Ed.: M. di Prisco, R. Felicetti and G.A. Plizzari Fibre-Reinforced Concretes, BEFIB 2004, Proceedings of the Sixth International RILEM Symposium, PRO 39, September 2004, varenna (LC), Italy, RILEM Publications S.A.R.L., pp. 985 – 994.

[16] ŠUŠTERŠIČ J., ZAJC A., LESKOVAR I., DOBNIKAR V. Influence of FRC Mix Proportion with Low Content of Short Fibres on the Crack Opening Resistance. Ed.: M. di Prisco, R. Felicetti and G.A. Plizzari Fibre-Reinforced Concretes, BEFIB 2004, Proceedings of the Sixth International RILEM Symposium, PRO 39, September 2004, varenna (LC), Italy, RILEM Publications S.A.R.L., pp. 995 - 1004.

[17] ŠUŠTERŠIČ, J., ZAJC, A., LESKOVAR, I.. Industrial floors for extreme loads. V: SEIDLER, P... (ed.). Industrieböden ’99 : internationales Kolloquium, 12.-14. Januar 1999. Band 2 : international colloquium, January 12-14, 1999. Vol. 2., 1999, pp. 927-931.

[18] ŠUŠTERŠIČ, J., LESKOVAR, I., ULJAREVIĆ, M., UKRAINCZYK, V., BADRLICA, J. Stahlfaser-Spitzbeton für die Auskleidung eines Kraftwerkstollens : Grundlagen des Programms zur Ausführung der Versuchsfelder und Intersuchungen. Zem. Beton (Vienna), 1991, no. 2, pp. 20-21.

[19] UKRAINCZYK, V., ULJAREVIĆ, M., ŠUŠTERŠIČ, J, ZAJC, A. Tragfähigkeit einer Faser-Spitzbeton-Auskleidung für einen Kraftwerkstollen. Zem. Beton (Vienna), 1992, št. 1, pp. 27-30.

[20] ŠUŠTERŠIČ, J., ZAJC, A., ERCEGOVIČ, R., RIČEK, F., HUDEJ, M. Quality assurance in production of dry shotcrete mixtures. V: Dhir, R. K. (ed.), Hewlett, P. C. (ed.), Csetnyi, L. J. (ed.). Innovations and developments in concrete materials and construction : proceedings of the International Conference held at the University of Dundee, Scotland, UK on 9-11 September 2002. London: Thomas Telford, 2002, pp. 937-947.

[21] ŠUŠTERŠIČ, J., ZAJC, A. Concrete ductility as a parameter for designing of tunnel and mine roadway linings. V: Kostiov, L. (ed.). Proceedings. of 6th International Symposium on Tunnel Construction and Underground Structures,Ljubljana: University, 2002, pp. 347-354.

[22] ŠUŠTERŠIČ, J., ZAJC, A., DOBNIKAR, V.. Bridge deck overlays made by HP-FRC. V: DHIR, Ravindra K. (ur.). Proceedings of the international conference held at the University of Dundee, Scotland, UK on 8-9 July 2008 : Concrete Durability - Achievement and Enhancement. Bracknell: IHS BRE Press, 2008, str. 373-382