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PRESTRESSED TEXTILE REINFORCED CONCRETE WITH CARBON COMPOSITE REINFORCEMENT

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Abstract. The article deals with the potential of prestressed textile concrete. The prestressing principle, which is nowadays commonly used part of construction, is combined with the developing technology of textile concrete which is concrete reinforced with non-metallic reinforcement. In this case the carbon reinforcement is used because it shows the best mechanical parameters in comparison with glass or basalt reinforcement. The paper presents the advantages of using prestressed textile carbon composite reinforcement of textile reinforced concrete and at the same time deals with problems related to it, such as the correct choice of impregnation using epoxy resin and the technological method of introducing prestress into the sample. The article focuses on comparison between 3 types of epoxy resin, specifically Sikafloor 156, LH 300 and EPOREZIT EPOVILL-A. The results are presented on experimental samples tested in four-point bending test.

Keywords: HPC, textile reinforcement, prestressed concrete, prestressing form, epoxy resin.

1. Introduction

The principle of prestressed concrete is based on concrete's relatively hight compressive strength and its very low tensile strength. The main principle is that compressive stress is brought into the concrete before it is loading and due to this the compress reserve is created. It results into better loading capacity of concrete in bend and many other advantages, for example better durability [1]. In commonly used prestressed concrete the prestress is created by steel-based prestressing reinforcement, anyway this paper deals with replacement of this type of reinforcement by CFRP. In case of this article the HPC is used, which in combination with CFRP prestressing reinforcement allows creation of very thin concrete construction elements. CFRP reinforcement displays different properties depending on type of used epoxy resin, so the main purpose of this paper is comparison of three different epoxy resin [2]. Concretely Sikafloor 156, LH 300 and EPOREZIT EPOVILL-A which were used for homogenization of carbon fibres. A total of 6 sets of samples were made, 2 for each type of epoxy resin, of which there was always one set of samples with non-prestressed reinforcement and one set with pre-stressed reinforcement. This article was written based on the data obtained as part of the diploma thesis "Production of prestressed textile reinforced concrete slabs" written by Tomáš Blažek in 01/2020 [3]. The topic of prestressing of concrete structures by composite reinforcement was investigate by many scientists, for example Amr A. Abdelrahman, Sami H. Rizkalla [4], Yunxing Du, Mengmeng Zhang, Fen Zhou, Deju Zhu [5] and many others [6, 7]. This paper builds on findigs of these researchers and continues in investigation of he given issue.

2. Materials and samples

2.1. High performance concrete

The samples are created from HPC, specifically from the HPC who's mix design is listed below in Table 1. This mixture was developed in department of civil engineering at CTU in Prague and later improved in UCEEB at Buštěhrad. The cubes of dimensions approximately $100 \times 100 \times 100$ mm and the beams of dimensions approximately $40 \times 40 \times 160$ mm were created to determine the properties of concrete.

Mix content	**kg m^{-3}**
Cement I 42.5R	689
Technical silica sand	975
Elkem microsilica 940 U-S	177
Technical quartz powder ST 6	329
Superplasticizer based on PCE	29.4
Water	173
Total	2 372.4

Table 1. HPC mix design [3].

The cubes were tested in compression according to ČSN EN 12390-3 [8] and the beams were subjected to three-point bending test according to ČSN EN

	Testing time [days]	a [mm]	b [mm]	h [mm]	F_{crit} [N]	$\sigma_{crit,c}$ [MPa]	$\sigma_{avg,c}$ [MPa]
KR1.01	3	100	100	99.89	517 231.9	51.78	52.14
KR1.02	3	100	100	99.71	522 391.1	52.39	
KR1.03	3	100	100	101.2	528 902.4	52.26	
KR2.01	10	100	100	100.9	1 264 599.2	125.33	118.15
KR2.02	10	100	100	99.7	1 119 892.7	112.33	
KR2.03	10	100	100	103.6	1 210 052.9	116.80	
KR3.01	28	100	100	101.7	1 400 021.3	137.66	130.40
KR3.02	28	100	100	101.9	1 310 562.5	128.61	
KR3.03	28	100	100	103.3	1 290 451.6	124.92	

TABLE 2. Pressure strength [3].

	Testing time [days]	a [mm]	b [mm]	h [mm]	F_{crit} [N]	$\sigma_{crit,c}$ [MPa]	$\sigma_{avg,c}$ [MPa]
TR1.01	3	40	39.98	160	1 764.9	4.14	4.60
TR1.02	3	40	38.78	160	2 055.1	5.12	
TR1.03	3	40	39.49	160	1 889.2	4.54	
TR2.01	10	40	40.02	160	3 399.8	7.96	7.93
TR2.02	10	40	40.12	160	3 123.9	7.28	
TR2.03	10	40	39.97	160	3 638.2	8.54	
TR3.01	28	40	40.01	160	6 501.6	15.23	15.83
TR3.02	28	40	40.36	160	6 962.0	16.03	
TR3.03	28	40	40.21	160	7 001.7	16.24	

TABLE 3. Tensile strength after bending [3].

12390-5 [9]. The tests were performed in three times steps, specifically 3 days after concreting, 10 days after concreting and 28 days after concreting. The results of the performed tests are shown in the Tables 2 and 3.

2.2. CARBON FIBRE REINFORCED POLYMER

As a prestressing reinforcement is used a composite reinforcement consisting of epoxy resin and carbon fibres 1 600 tex (which means that 1 km long roving weights 1 600 kg). Three types of rovings were tested to demonstrate, why is the epoxy resin so important. The first was roving without any other improvements, the second was roving which was twisted and the third was roving impregnated with epoxy resin.

As you can see in the Figure 1, the epoxy impregnated rovings were able to transfer more than double the force compared to the unimpregnated rovings.

2.3. EPOXY RESINS

2.3.1. SIKAFLOOR 156

Two-component epoxy resin, which is most often used for the penetration of concrete substrates and cement screeds. The ratio of filler and hardener is 3:1. In this ratio, the adhesive exhibits the best mechanical parameters. The tensile strength specified by the manufacturer is 1.5 MPa. This information was taken from the manufacturer's data sheet.

2.3.2. LH 300 + HARDENER H 287

Very high-quality, medium-viscosity, low-molecular resin for lamination high resistance parts (up to 160 °C). This resin has been tested and used in the production of molds and parts for brake system cooling on Škoda Fabia WRC cars. Even though these parts were exposed to temperatures exceeding 250 °C and at the same time to constant impacts, they fully met the extreme requirements for strength and heat resistance. Temperature resistance of 160 °C is the temperature at which there are no changes in mechanical parameters and properties. This information was taken from the manufacturer's data sheet.

2.3.3. EPOREZIT EPOVILL-A

Epoxy to produce prepregs with increased heat resistance. It is important to work with it at a constant temperature and low air humidity. The main application of the system is in energy (transformers, power transistors), telecommunications industry, capacitors and other forms. The system cures only above 80 °C. The cured system may have an orange-red tint. This information was taken from the manufacturer's data sheet.

2.4. SAMPLES PRODUCTION

The design of the prestressing track was based on the design of W. Brameshuber and T. Brockmann [10, 11].

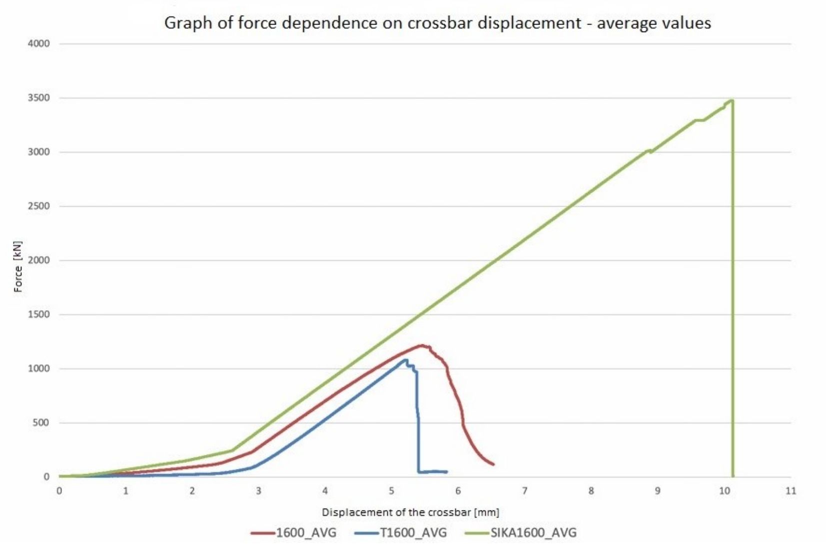

Figure 1. Graph of force dependence on crossbar displacement – average values [3].

The principle consists in clamping carbon rovings impregnated with epoxy resin into steel jaws and their subsequent displacement, thereby tensioning these rovings to the appropriate value. The problem with this system is how to measure the actual force applied to the roving and how to attach the roving to the jaws. In this case, the actual force transferred to the roving was calculated from the knowledge of the displacement of the cross member, the modulus of elasticity and the cross-sectional area. The calculated values were verified by strain gauges. The method of attaching the rovings to the jaws is problematic mainly because the ends of the rovings are crushed with a strong grip, and on the contrary, with a weak grip, slippage occurs at the attachment point. This problem was solved with chemical mortar sockets. The form was made in such a way that it was possible to concrete an element with dimensions of 20 × 100 × 1200 mm, which will then be divided into 3 samples of length 360 mm. The samples themselves were produced in the following way:

In the first step, the rovings were stretched and impregnated with epoxy resin. For streching the mold shown in the Figure 2 was used. The design of this mold is shown in the Figure 3. Subsequently, they were sandblasted to ensure sufficient cohesion with the concrete matrix [12]. Heat-cured epoxy resins were cured in a laboratory oven. After the epoxy dried, the rovings were cut from the mold and chemical mortar sockets were made on one side of the rovings. Then the rovings were stretched, sockets were also made on the other side of the rovings, and then the final tensioning took place. The reinforcement prestressed in this way was left at rest for 3 days and the stress drop was continuously monitored. After approximately 48 hours, the tension value stabilized and thus concreting was possible on the 3rd day after tensioning of the reinforcement. The introduction of tension was carried out 3 days after concreting, after

Figure 2. Final mold [3].

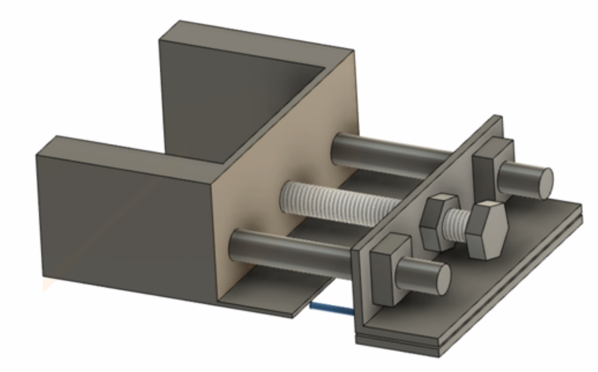

Figure 3. Prestressing mold desing [3].

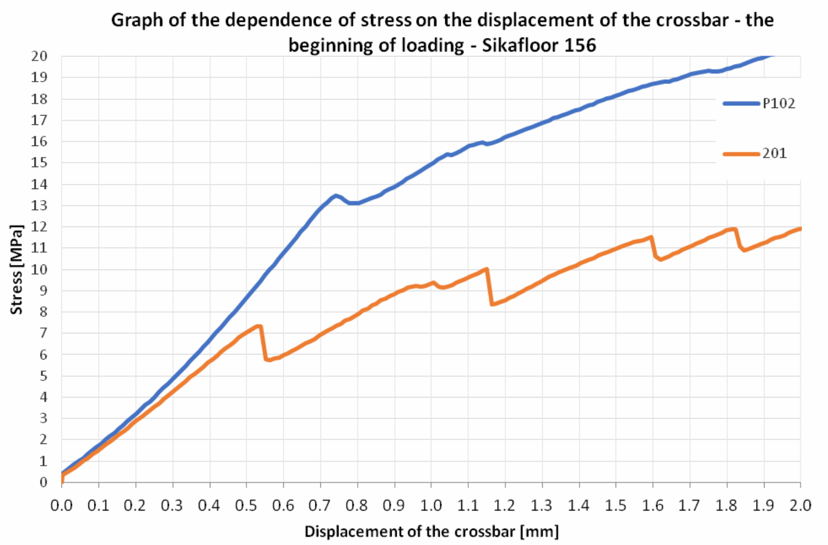

FIGURE 4. Graph of the dependence of stress on the displacement of the crossbar – the beginning of loading – Sikafloor 156 (blue – prestressed, orange – not prestressed) [3].

another 3 days the formwork was removed, and the samples were tested 28 days after concreting [3].

2.5. EXPERIMENT

To verify the prestressing potential of textile concrete, a 4-point bending test was performed. The loading speed was chosen to be $0.02\,\mathrm{mm\,s^{-1}}$. All testing took place at the Faculty of Civil Engineering of the Czech Technical University in Prague. You can see a photo from the experiment in the Figure 5.

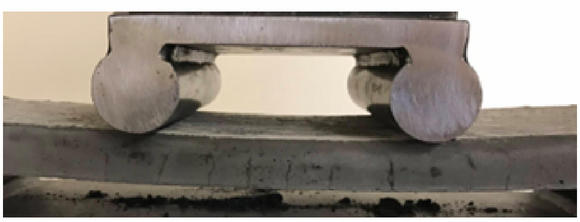

FIGURE 5. Photo from the experiment [3].

3. RESULTS

3.1. SIKAFLOOR 156

From the graph of the dependence of the stress on the displacement of the cross member shown in the Figure 4, it follows that the load-bearing capacity of the prestressed elements is increased, and it is evident that after the appearance of the first crack, there is a more massive development of cracks with a significant opening in the non-prestressed elements. This fact clearly proves the positive effect on the formation of the first crack.

3.2. LH 300

The prestress in this case shows the same positive effect that was also noted with the Sikafloor 156 epoxy resin. The dependence of the stress on the displacement of the crossbar from the beginning of the loading is shown in the graph in the Figure 6.

3.3. EPOREZIT EPOVILL-A

Even in the case of the last epoxy resin, the positive effect is the same as in the previous cases.

As can be seen from the results shown in the Figure 7, prestress losses occurred in all variants in time. The causes will be discussed in the following text. There were the lowest losses achieved in samples where LH 300 resin was used. The worst results are achieved when using Sikafloor 156 epoxy resin. Comparison of all prestressed samples is shown on the graph in the Figure 8.

Prestress losses of individual samples were calculated according to the following formulas:

$$\sigma_{Mf} = \frac{M_f}{W}, \tag{1}$$

$$\Delta\sigma = (\sigma_{res} + \sigma_t) - \sigma_{Mf}, \tag{2}$$

where:

σ_{res} – pressure reserve,
σ_t – tensile stress after bending,
σ_{Mf} – tensile stress from the loading,
$\Delta\sigma$ – prestress loss.

The prestress losses results are shown in the Table 4.

4. CONCLUSION

The choice of resins turns out to be successful, mainly due to small stress losses. Above all, the LH 300 resin showed minimal stress losses. Overall, it can be stated that the prestress is characterized by a shift in origin the first cracks and by eliminating the formation of other massive cracks after their formation. The fundamental effect of the preload is therefore on the

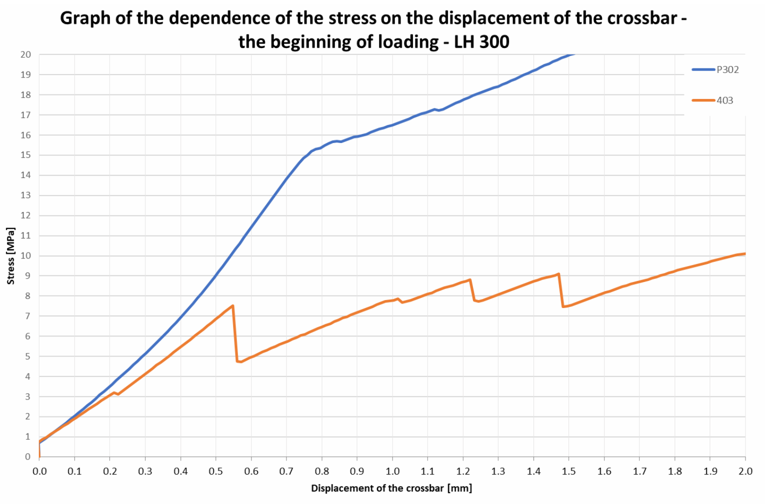

Figure 6. Graph of the dependence of stress on the displacement of the crossbar – the beginning of loading – LH 300 (blue – prestressed, orange – not prestressed) [3].

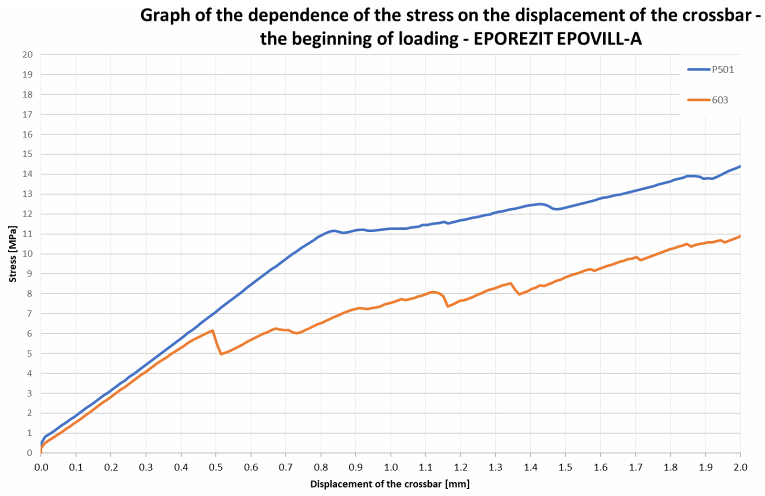

Figure 7. Graph of the dependence of stress on the displacement of the crossbar – the beginning of loading – EPOREZIT EPOVILL-A (blue – prestressed, orange – not prestressed) [3].

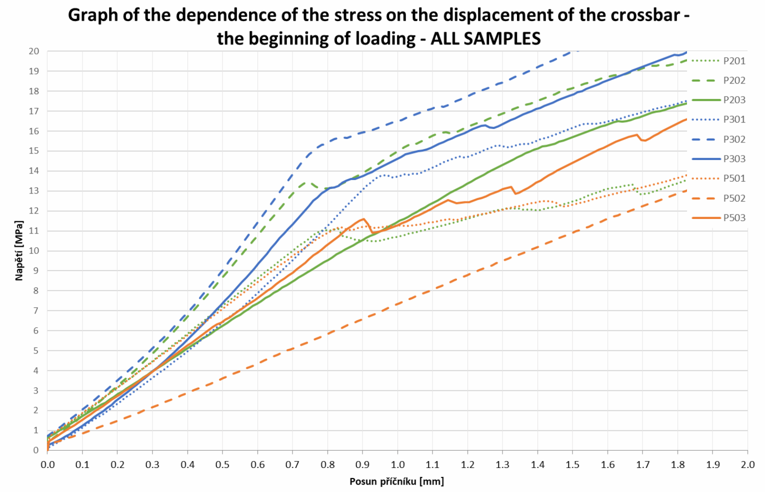

Figure 8. Graph of the dependence of stress on the displacement of the crossbar – the beginning of loading – all prestressed samples (blue – LH 300, green – EPOREZIT EPOVILL-A, orange – Sikafloor 156) [3].

Resin type	**Sample number**	b [mm]	h_{avg} [mm]	A_c [mm^2]	F_{first} [N]	L [mm]	M_f [Nm]	e_d [mm]	e_p [mm]	W [mm^3]	I [mm^4]	P [N]	σ_{res} [MPa]	σ_t [MPa]	σ_{Mf} [MPa]	$\Delta\sigma$ [MPa]	**Std dev**
SIKA sikafloor	2.01	100.0	20.9	2 090.0	1 241	100.0	62.1	10.5	3.5	7 280.2	76 077.7	3 248	3.12	7.93	8.52	2.52	0.29
	2.02	100.0	20.6	2 062.0	1 402	100.0	70.1	10.3	3.5	7 086.4	73 060.9	3 248	3.18	7.93	9.89	1.22	0.46
	2.03	100.0	20.8	2 084.3	1 267	100.0	63.4	10.4	3.5	7 240.7	75 460.6	3 248	3.13	7.93	8.75	2.31	0.17
LH 300	3.01	100.0	26.7	2 670.0	2 340	100.0	117.0	13.4	3.5	11 881.5	158 618.0	3 067	2.05	7.93	9.85	0.13	0.03
	3.02	100.0	25.1	2 510.0	2 100	100.0	105.0	12.6	3.5	10 500.2	131 777.1	3 067	2.24	7.93	10.00	0.17	0.01
	3.03	100.0	18.9	1 890.0	1 320	100.0	66.0	9.5	3.5	5 953.5	56 260.6	3 067	3.43	7.93	11.09	0.27	0.04
LEPO-REZIT epovill-A	5.01	100.0	21.7	2 166.3	1 293	100.0	64.7	10.8	3.5	7 821.7	84 721.7	2 995	2.72	7.93	8.27	2.39	0.35
	5.02	100.0	23.7	2 373.7	1 539	100.0	76.9	11.9	3.5	9 390.5	111 449.5	2 995	2.38	7.93	8.19	2.11	0.20
	5.03	100.0	22.8	2 275.7	1 664	100.0	83.2	11.4	3.5	8 631.1	98 207.5	2 995	2.53	7.93	9.64	0.82	0.55

TABLE 4. Prestress losses [3].

durability of the structure as well as on the design of subtle elements and the maximization of the use of the compressive strength of concrete. Fundamental questions that would enable more frequent use of this type of construction is still a large number and dynamic stress, fire resistance are worth mentioning and tests that consider the durability of the structure [3].

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