DEVELOPMENT OF SPECIAL FIBRE-REINFORCED CONCRETE FOR EXPOSED CONCRETE PAVEMENTS ON BRIDGES

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Abstract

Most of standard concrete bridges are currently composed of three parts: load-bearing structure, water-proofing layer and wearing surface. The authors of the paper decided to pursue an idea of a special fibre-reinforced concrete mix that would meet the requirements for all parts of the structure – to provide sufficient load-bearing capacity, to secure water-proofing of the structure, to give enough wearing resistance and resistance to freeze-thaw cycling in the presence of deicing chemicals. The objective of the research was to find a cementitious composite with the ability to withstand the effects of all the severe environmental conditions without the need to use additional asphalt or polymer protective layers. In future, the material could be exploited to build cheaper and more efficient structures thanks to elimination of some construction layers, simplification of construction process and reduction of required works.

To develop the composite with the abovementioned qualities, extensive experimental program was carried out. Slump, air content, compressive strength, flexural strength, elastic modulus, resistance to water and deicing chemicals and depth of penetration of water under pressure were measured. The mix composition was initially estimated based on the extensive literature survey and experience of the authors and later adjusted several times to obtain characteristics meeting the requirements given by Technical Specifications of Ministry of Transport of the Czech Republic, chapter 18 (TKP 18). The use of polymer fibres proved to be an effective measure for improving the durability of the material. The final mix complies with all the main requirements defined for reinforced concrete bridges with exposed pavements.

Keywords: Pavements on bridges, fibre reinforced concrete, resistance to water and deicing chemicals, depth of water penetration

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1. Introduction

Most of standard concrete bridges are currently composed of three parts. The first one is the load-bearing structure – the concrete used is characterized by high strength and elastic modulus. The second part is water-proofing layer that should shield the load-bearing structure against the effects of water and aggressive chemical agents used for maintenance during the winter period. This layer is usually composed of asphalt or polymer based materials. The third one is the wearing surface that protects the two parts mentioned before from the influence of conveyance. Wearing surface must be resistant to the environmental loads and abrasion. Therefore, flexural strength and resistance to deicing chemicals of the material must be maximized, while cracking due to temperature changes and shrinkage must be minimized.

The authors of the paper decided to develop a special fibre-reinforced concrete mix that would meet the requirements for all parts of the structure – to provide sufficient load-bearing capacity, to secure water-proofing of the structure and to provide enough wearing resistance and durability of the surface. This was not an easy task as the concrete has to meet the requirements for the most severe exposure classes according to ČSN EN 206 [2] – XC4, XF4 and XD3. The mix also has to comply with the demands on workability of fresh concrete (pumping, compacting by immersion vibrators). The use of polymer fibres proved to be an efficient measure to accomplish the required properties.

Exposed concrete pavements are quite common on bridges in the North America, however, they are rarely used in Europe. The objective of the research was to develop a material that would enable financial savings thanks to elimination of asphalt and polymer layers, simplification of construction process and reduction of required works.

Fig. 1: Exposed concrete pavement on bridge over Wilson Creek, Montgomery County, Virginia, USA [1].

2. Experimental program

2.1 Concrete mix composition

Initial design of the composition of concrete was based on the information from the North American literature. The material was further adjusted according to the experience of the authors. Fibres were added to the mix to prevent excessive surface cracking due to shrinkage and to increase abrasion resistance of the exposed pavement. The dosage of individual components was continuously adjusted according to the results of the experiments to meet all the necessary requirements.

Tab.1: Final composition of the material.

Component	Specification	Dosage [kg/m^3]
cement	CEM I 42.5 N (Mokrá)	400
water	-	176
fine aggregate	0/4 (Křenek)	800
middle aggregate	4/8 (Křenek)	200
coarse aggregate	8/16 (Plaňany)	680
air-entrainer	Centrament Air 202	0.4
superplasticizer	Stachement 2090	2.4
fibres	Forta Ferro	3.0

2.2 Properties of fresh concrete

As the concrete is usually placed by pumps and compacted by immersion or surface vibrators in bridge structures, a mix with sufficient workability had to be designed. According to ČSN EN 12350-2 [5], a slump of 140 mm was achieved, corresponding to S3 class.

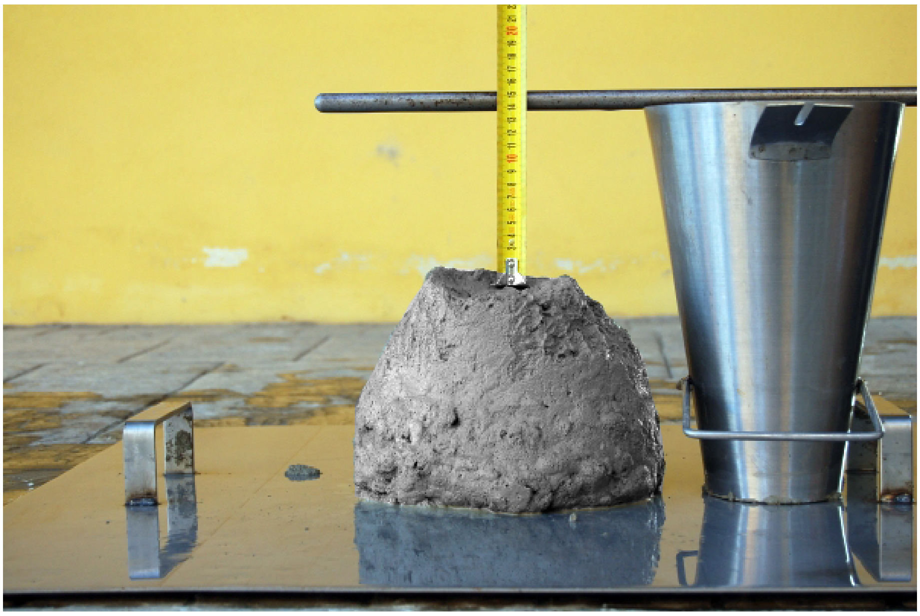


Fig. 2: Result of slump-test: 140 mm correspond to S3 class.

For XF4 exposure class and maximum aggregate size of 16 mm, a minimum air content in fresh concrete of 4.5 % according to ČSN EN 12350-7 [6] is required by TKP 18 [3] to provide sufficient resistance to freeze-thaw cycling. An average of 5.86 % was reached for the investigated mix.

Tab. 2: Air content measured on the specimens.

Specimen no.	1	2	3	4	5	Average
Air content [%]	5.5	6.2	5.9	5.6	6.1	**5.86**

2.3 Compressive strength

For the required exposure classes, minimum concrete class is defined as C30/37 by TKP 18 [3]. The compressive strength was measured on 150 mm standard cubes according to ČSN EN 12390-3 [7]. Characteristic value of 46.25 MPa was determined based on the mean value, standard deviation of the measured values and Student's statistical coefficient k_n = 2,63. This leads to C35/45 concrete class.

Tab. 3: Compressive strength measured on cubes.

Specimen	Geometry			Bulk density [kg.m^{-3}]	Max. force [kN]	Compressive strength [MPa]
	Height [mm]	Width [mm]	Length [mm]			
1	147.8	150.1	150.7	2268	1141.8	51.5
2	148.7	150.3	150.2	2280	1138.4	50.9
3	149.9	150.2	150.1	2296	1115.0	49.5
4	145.0	150.1	150.4	2286	1181.6	54.3
Average	-	-	-	**2282**	-	**51.6**

2.4 Flexural strength

An average of 3.43 MPa was measured on 100x100x400 prisms subjected to three point bending according to [8]. There are no limits given for the flexural strength by TKP 18 [3], but according to handbook [15], flexural strength of 2.5 – 4.5 MPa should be provided for sufficient abrasion resistance of the surface loaded by regular traffic.

The load-deflection curves obtained from the tests have also proven significant ductility of the material which is important for prevention of excessive width of cracks.

Tab. 4: Flexural strength measured on prisms.

Specimen no.	1	2	3	**Average**
Flexural strength [MPa]	3.54	3.19	3.56	**3.43**

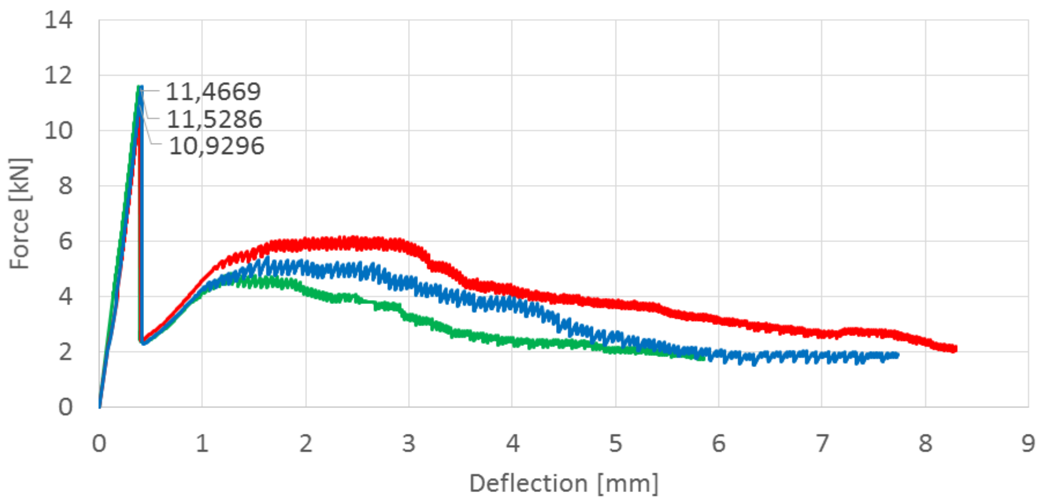


Fig. 3: Load–deflection diagrams of the specimens.

2.5 Abrasion resistance

Surface of a concrete bridge deck subjected to vehicles with tyres should meet the requirements for exposure class XM1 according to ČSN EN 206-1/Z3 [12]. This means that the concrete class should be at least C30/37. This criterion is met.

According to DIN 1045 [13], abrasion measured on Böhme testing device according to ČSN 73 13 24 [14] should not exceed 12 $mm^3/50\ cm^2$ for XM1 exposure class. According to the experience of the authors, this is a very benevolent criterion that will be met by any concrete of class higher than C20/25. Considering the values of compressive strength listed in table 3, it was decided not to conduct the abrasion resistance tests on Böhme device as they are very time consuming.

2.6 Elastic modulus

Elastic modulus was determined on standard 150x300 mm cylinders according to ČSN EN 12390-13 [9]. The average value was 26.93 GPa.

Tab. 5: Elastic modulus measured on cylinders.

Specimen no.	1	2	3	**Average**
Elastic modulus [GPa]	26.85	27.69	26.27	**26.93**

The obtained value is very low, a result in the range of 30 – 34 GPa was expected for C35/45 concrete. The reason for the poor outcome of the test is the fact that the cylinder specimens were not compacted properly; bulk density was just 2074 $kg.m^{-3}$ compared to 2282 $kg.m^{-3}$ reached in cubes for compressive strength tests. Even though there is no requirement on the elastic modulus given by the TKP 18 technical specifications, the value is very important for the structural analysis. Therefore the tests should be repeated in the future.

2.7 Depth of penetration of water under pressure

The depth of penetration of 32.6 mm after 72 hours of exposure to water under pressure was measured according to ČSN EN 12390-8 [11]. This is in accordance with the requirement of ČSN EN 206-1/Z3 [12] for the structures in XF4 environment with expected service life of 50 years (35 mm). The requirement for service life of 100 years (20 mm) was not met. However, it is not a problem in this case. The depth of penetration is limited mainly because of corrosion protection of the reinforcement. As the secondary protection of reinforcement by epoxy coatings is required anyway on the upper surface of concrete bridges with exposed pavements, the value reached in the test is sufficient.

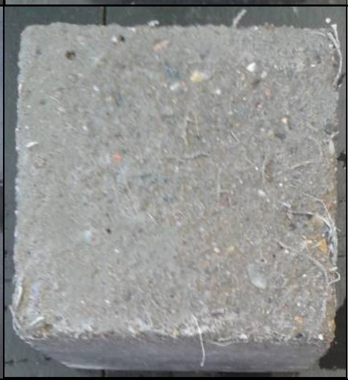
Tab. 6: Depth of penetration of water under pressure.

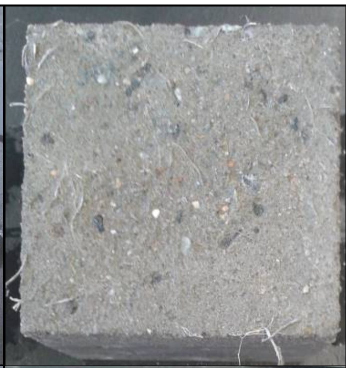
Specimen no.	1	2	3	**Average**
Depth of penetration [mm]	32	35	31	**32.6**

2.8 Resistance of concrete surface to water and deicing chemicals

The measurement was conducted on 150 mm cubes in KD 20.4 testing device according to ČSN 73 1326 [10], method A. The freeze-thaw cycling was conducted in two steps (0 – 50 cycles and 51 – 100 cycles), after each step the scaling was measured. The limit of 1000 g per m^2 after 100 cycles given by TKP 18 [3] was met with substantial margin.

Tab. 7: Resistance to water and deicing chemicals – results.

Specimen no.	Surface after 50 cycles	Surface after 100 cycles	Scaling after 100 cycles [g/m^2]	Evaluation after 100 cycles
1			745	disturbed
2			545	disturbed
3			706	disturbed
4			847	disturbed

5			631	disturbed
6			~~161~~	~~slightly disturbed~~ (invalid specimen)
Average	-	-	**695**	-

3. Conclusions

The following table summarizes the requirements on properties of exposed pavements on concrete bridges and characteristics measured for the developed material.

Tab. 8: Overview of properties of the developed material.

Characteristic	**Measured value**	**Requirement given by**	**Required value**	**Met?**
Cement content	400 kg/m^3	TKP 18	min. 340 kg/m^3	**OK**
Water/cement ratio	0.42	TKP 18	max. 0.45	**OK**
Slump-test	140 mm	Workability needs	100 – 150 mm	**OK**
Air content	5.86%	TKP 18	min. 4.5 %	**OK**
Compressive strength	C 35/45	TKP 18	min. C 30/37	**OK**
Flexural strength	3.43 MPa	Handbook [15]	min. 2.5 MPa	**OK**
Abrasion resistance	C35/45	ČSN EN 206-1/Z3	min. C30/37	**OK**
Elastic modulus	26.93 GPa	Structural analysis	32 MPa	**NO**
Resistance to water and deicing chemicals	695 g	TKP 18	max. 1000 g/m^2	**OK**
Depth of penetration of water under pressure	32.6 mm	ČSN EN 206-1/Z3	max. 35 mm	**OK**
		TKP 18	max. 20 mm	**NO**

It is clear that the material met all the requirements with the exception of two of them. In case of elastic modulus, the specimens failed due to poor compaction – bulk density of the cylinders used for the tests was almost 10 % lower than what it should have been. This problem would be probably eliminated by repeated tests. In case of depth of penetration of water under pressure, the limit for 100 years service life was not met, therefore the risk of corrosion of reinforcement is increased. This problem could be eliminated e.g. by the use of epoxy coated reinforcement – secondary protection of reinforcement is required anyway for bridges with exposed pavements.

Acknowledgements

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