TESTS ON SIMPLE SPECIMENS MADE OF UHPC

VÍTEK, Jan L.[1], COUFAL, Robert [2], STAŠ, Martin [3], KOLÍSKO, Jiří [4]

Abstract

Ultra high performance concrete under consideration is made of the local constituents. It is designed as ready mixed concrete, which can be also used as self-compacting concrete. Some material tests are described. The performance of UHPC in anchorage zones of prestressing bars was experimentally verified. The thin slab exhibited excellent resistance in punching.

Keywords: Anchorage zone, crack, fibre, punching, ultra high performance concrete

1. Introduction

Ultra high performance concrete (UHPC) is a new and promising material. First applications are more than 20 years old. The development of concrete technology leads to the development of the material worldwide. Some applications are based on the prepared concrete mix, which is distributed and mixed only with water and then used (e.g. Ductal). The other way is developing of UHPC from local constituents. The team of Metrostav and TBG Metrostav is convinced that the application of local materials is the right way for production of a competitive material. The research is focused on ready mixed UHPC, which can be transported with truck mixers to remote sites. The criteria for the UHPC under development were settled as follows: compression strength measured on standard cylinders higher than 150 MPa, flexural strength higher than 15 MPa and the water cement ratio should be less than 0.25.

2. Development of the concrete composition

The development started with evaluation of properties of materials available in the Czech Republic. The variety of constituents was carefully observed. The cement composition was checked for different cement types including CEM I 52,5, CEM I 42,5 and CEM III 32,5. Surprisingly all cements are able to satisfy the conditions of high strength of concrete. Different aggregates were tested and the optimal granulometry was searched. The fine particles – microsilica and other constituents were tested concerning the interaction with

[1] VÍTEK, Jan L., Metrostav a.s. and CTU Prague, Koželužská 2246, 180 00 Praha 8, vitek@metrostav.cz

[2] COUFAL, Robert, TBG Metrostav, s.r.o., Rohanské nábř. 68, 186 00 Praha 8, robert.coufal@tbg-beton.cz

[3] STAŠ, Martin, Metrostav a.s., Div.5, Na Zatlance 13, 150 00 Praha 5, martin.stas@metrostav.cz

[4] KOLÍSKO, Jiří, Klokner Inst., CTU Prague, Šolínova 7, 166 08 Praha 6, kolisko@klok.cvut.cz

admixtures and cement. The first tests were made on small mortar specimens. About 30 different mixtures were evaluated in terms of workability and mechanical properties of hardened mortar. The final step – development of concrete mix – is very sensitive to the mixing process. The type of mixer is essential for the quality of concrete. Therefore it was necessary to make all tests in a large mixing plant which is used for everyday production. Finally various types of fibres were tested. After evaluation of many alternatives, the successful concrete composition satisfying the required conditions was found.

Transport and pouring of UHPC into formwork were verified on the panels 3 m long. The surface exposed to the environment has to be cured very carefully. It has been found that the self-compacting UHPC is the most convenient alternative, which allows for relatively fast casting process with a limited impact of human factor. This leads to better quality of the structure. Self-compacting UHPC also allows for casting of elements of complex shapes and with embedded steel elements or with dense reinforcement.

3. Testing of material properties

Material properties are tested in a fresh state and in a hardened state. Properties of fresh concrete are verified by slump flow tests, sometimes by J-ring, which is convenient for verification of blocking in reinforced elements. For the transport to the site, the time of workability is important. The times up to 90 minutes are sufficient for usual applications. At some applications the development of hydration heat is important. Temperature development can be measured on the cube 300 x 300 x 300 mm, which is completely isolated from the ambient environment. The example of measured temperature variation is illustrated in Fig.1.

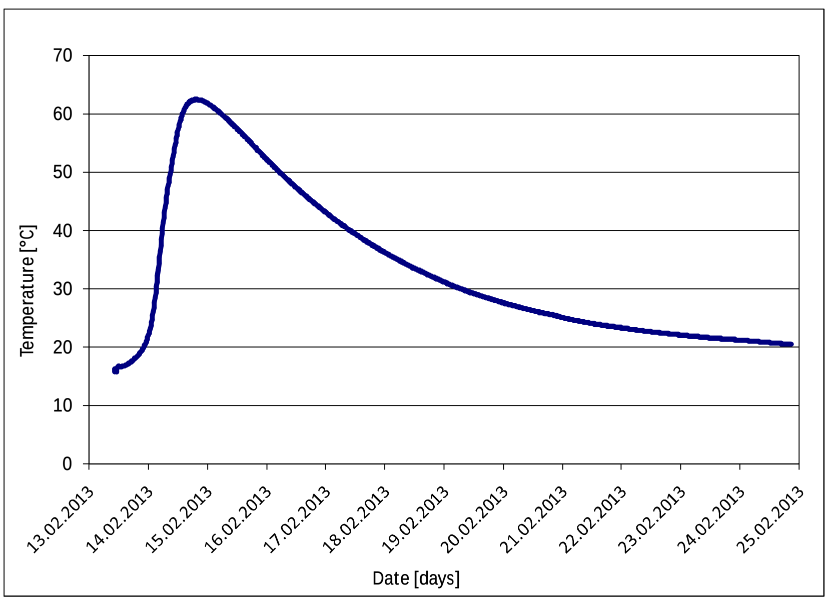

Fig. 1: Temperature variation due to heat of hydration

The compression strength of UHPC is tested on different specimens. The compression strength measured on standard cylinders (150 x 300 mm) is taken as the reference compression strength. The compression strength measured on other specimens provides different values. Especially, if the cube is small the measured strength grows. For practical verification of strength in construction process the tests on cubes 100 x 100 x 100 mm is convenient. The loading force is smaller and the quality of loaded surfaces is acceptable. If the cylinder strength is measured, the loaded surfaces must be carefully treated in order to get precisely parallel areas. The cubes 150 x 150 x 150 mm are not so convenient because the loading force becomes rather large and the machines, which are in most of the laboratories, are not able to develop sufficient force for crushing of the cube.

The elastic moduli are measured on standard cylinders similarly as it is used at ordinary concrete.

For design of structures the tensile properties are essential. In many cases the tension is carried only with fibres, because of absence of the reinforcement. There are two methods of testing the bending of beams made of UHPC. At both of them the bending test is executed on the beam 150 x 150 x 700 mm. The method according to the RILEM recommendations uses 3 point bending test with the notch, where the span of the beam is 500 mm. The German recommendations use 4 point bending test without any notch with the span of the beam 600 mm. The results may be slightly different, but in general both methods are equivalent. Fig. 2 illustrates the results using the RILEM 3 point bending test on notched specimen.

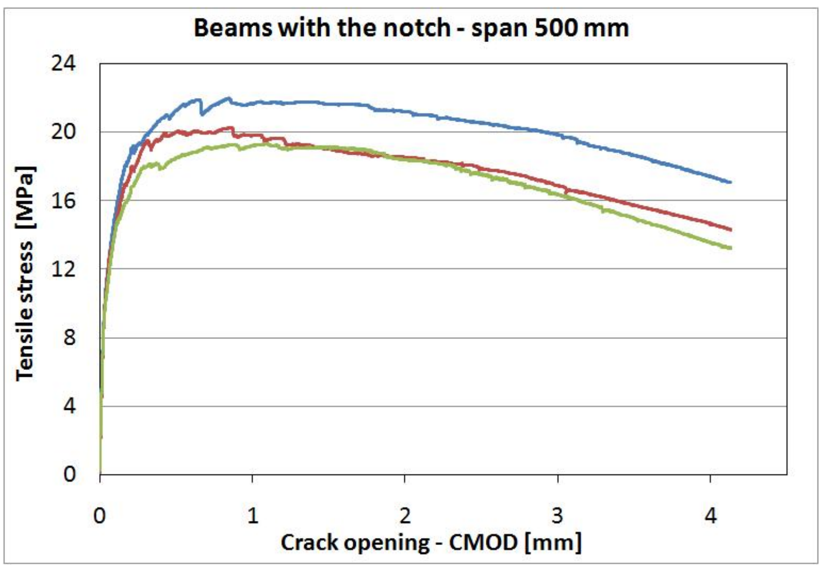

Fig. 2: Results of the bending test

The UHPC has excellent resistance against environmental impacts like frost and de-icing salts. The usual tests may be applied for UHPC, which prove its performance.

UHPC exhibits shrinkage which has a different development than ordinary concrete. The autogeneous shrinkage is larger and within few hours the strain reaches about 300 microstrain (μm/m). Fig. 3 shows the autogenous shrinkage strain development in time at the specimen cured in water. Then the drying shrinkage is comparable to that of ordinary concrete. The creep strain seems to be very small. Fig. 4 illustrates the measured strain of free and loaded cylinders. The loading force approx.100 kN is induced by steel springs. The slope of individual curves is very similar, which shows that the shrinkage is a dominant delayed strain of UHPC, while creep is smaller than that of the ordinary concrete.

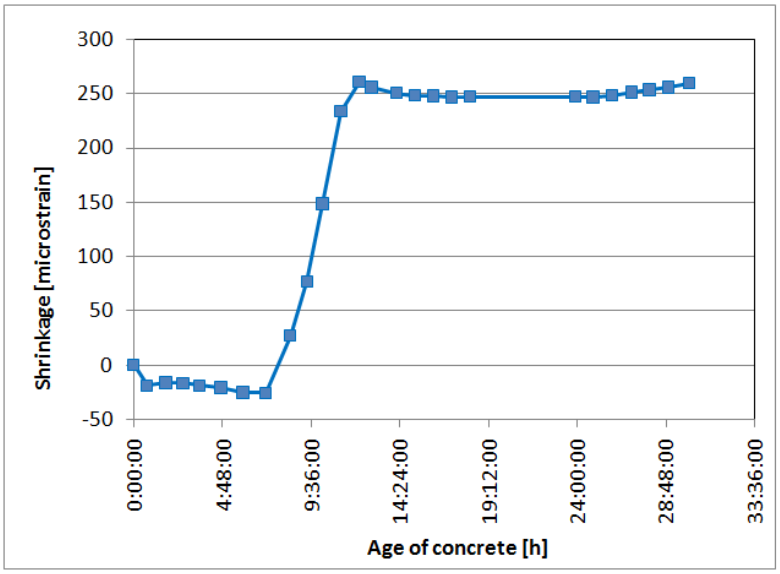

Fig. 3: Autogenous shrinkage (curing in water)

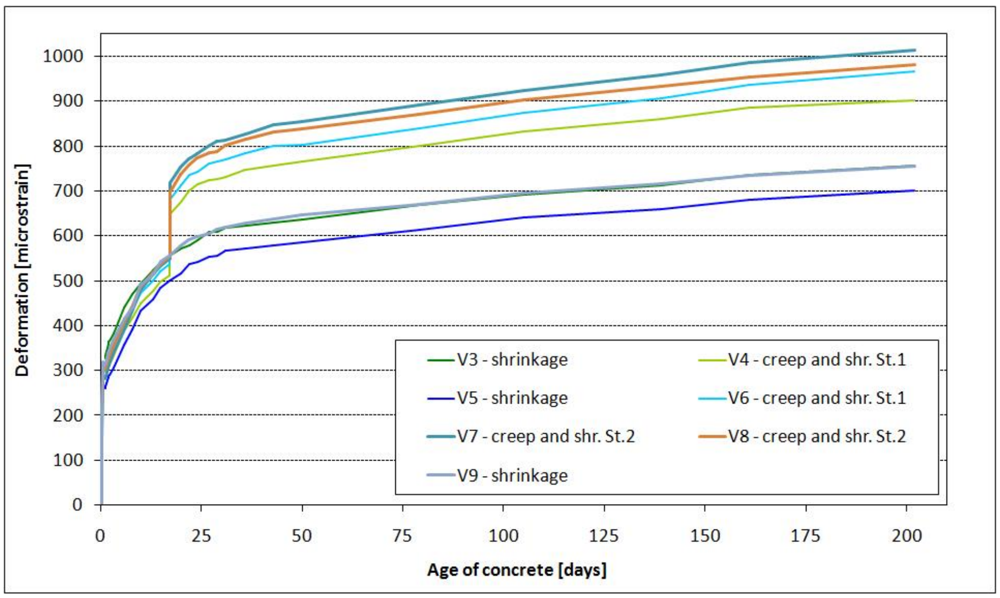

Fig. 4 Creep and shrinkage long-term strain

4. Anchorage zones

Anchorage zones of prestressing units are extremely loaded areas, which are usually reinforced with large amount of steel. The spiral shaped bars are used for transfer of tensile stresses in transversal direction. Such reinforcement is combined with other reinforcing bars. Great amount of steel results very often in poor filling the area with concrete. A large amount of fibres in UHPC is able to carry significant tensile stress under anchors. The bar reinforcement then can be reduced.

The anchorage zones under the anchors of prestressing bars were tested. In the first stage the bars 36 mm in diameter were used. The anchor plate has dimensions 140 x 140 mm and the characteristic prestressing force F_{pk} = 1069 kN. The testing procedure followed the ETAG 013 rules. The prisms had dimensions 200 x 240 x 500 mm. Two groups of specimens were produced: 1. Prisms without any bar reinforcement and 2. Prisms with 4 longitudinal bars and stirrups. The loading procedure started with repeated load of 0.8 F_{pk} = 855 kN ten times and then the load was increased until failure. The tests were carried out at the age of concrete 5 days.

At the specimens without reinforcement (with exception of fibres) no crack appeared during cyclic load and after increasing the load the first cracks were observed at the level of 1450 to 1600 kN, which is about 1.35 to 1.5 F_{pk}. Such load cannot appear in practical application at any case. The experiment was stopped at the level of loading 1.7 F_{pk}. Small cracks were observed and it was found unnecessary to continue with loading. Fig. 5 shows the test arrangement.

The specimens with stirrups had also no cracks during the cyclic loading and the first cracks were observed at the level of loading 1750 – 1850 kN (1.64 – 1.73 F_{pk}). The tests were finished at the load level of 2050 kN (1.92 F_{pk}).

The achieved values were higher than expected. The UHPC exhibited satisfactory results and it would be possible to omit all reinforcement in the anchorage zone. However, it may be recommended to use at least some reinforcement with respect to little experience with the new material.

Fig. 6: Test arrangement of the anchorage zone

5. Punching of the slab

The UHPC is used for production of segments of cable stayed footbridge. The segment has two longitudinal beams at the edges of the cross section connected by the slab 60 mm thick without any bar reinforcement. The slab is stiffened by transversal ribs in the distance about 980 mm. The footbridge will be used also for light vehicles up to 35 kN with axial load up to 25 kN. The slab was tested by a single load with the contact circular area (diameter of 200 mm). The test arrangement is plotted in Fig. 7. The load was subsequently located in 4 positions of the slab, so that 4 values of ultimate load would be obtained. 3 positions were close to the edge beam and 1 position was on the longitudinal axis of the footbridge. The loading procedure started by increasing the load up to 22 kN and unloading. This process was repeated 5 times. Such load represented higher load than that corresponding to the serviceability limit state.

No cracks appeared at repeated load level at all. Then the load was increased until failure. The first cracks appeared at the level of 197 kN, which is the load about 15 times higher than the static wheel load induced by the design vehicle. Finally the slab failed by punching at the load level of 372 kN, which is about 30 times more than the wheel load induced by the design vehicle. The failure by punching is illustrated in Figs. 8 and 9. The uniform fibre distribution can be seen in Fig. 9. Additional 3 tests exhibited very similar results. The first cracks were observed at the load level of 150 to 200 kN, the lower values were influenced by the drainage opening close to the loading point and by the edge span of the slab. However, the further tests were finished from the safety reasons at the load level of about 350 kN, without failure, and at the load level of 320 kN at the edge span of the slab, where the ultimate load carrying capacity is naturally smaller. The load carrying capacity was surprisingly high, which proved the reliability of the structure made of UHPC.

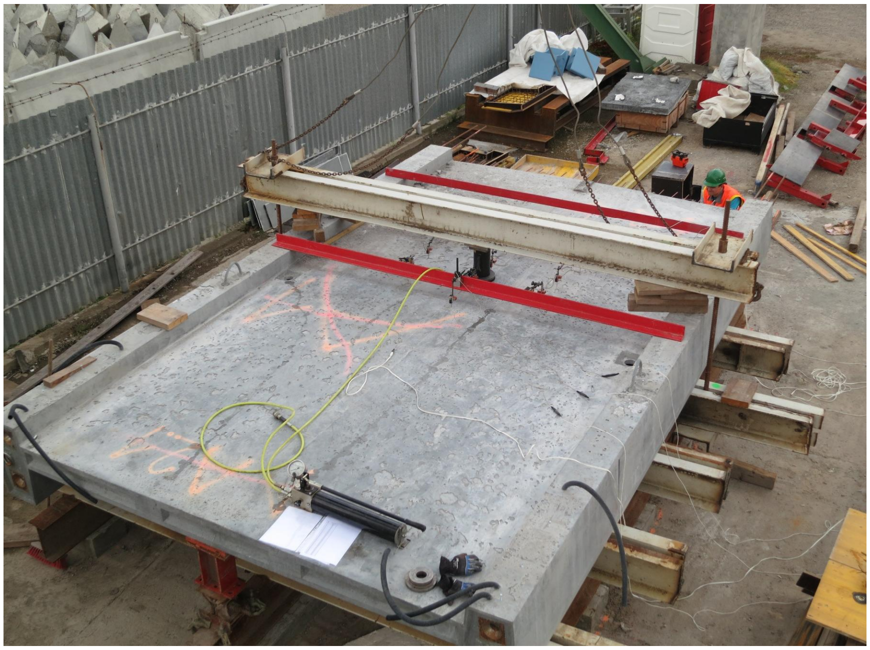

Fig. 7: The slab punching test arrangement

Fig. 8: Failure of the slab from the bottom

Fig. 9: Failure of the slab – detached concrete

6. Conclusions

The developed UHPC was tested as a material and also the performance of simple structural elements was verified. A careful design of concrete composition is a basic condition for high compression and tensile strength. The tensile strength may be significantly influenced by the selection of fibres. The heat of hydration developed during hardening is influenced mainly by the applied cement. The experiments showed that the autogenous shrinkage is rather large but the drying shrinkage is not too different form ordinary concrete. The measured creep was less than that of ordinary concrete.

The tests of anchorage zones of prestressed bars exhibited excellent performance. No cracks were found at the realistic load, which can occur during prestressing works, even in specimens without any bar reinforcement. The failure load would be higher than 1.6 times the characteristic prestressing force. It provides significant safety of the anchorage area.

The punching tests of the thin slab also proved significant safety reserve of the tested bridge deck. The smallest measured ultimate load was about 25 times higher than the wheel load of the design vehicle. It means that the slab should not be the weak point of the footbridge.

Although the tests provided very good results, it is necessary to think about the required reserves in design procedure. UHPC is a very good material but on the other hand the knowledge on its behaviour is still rather limited. It may be recommended that the usual safety reserves should be increased at the structures made of UHPC at least until the time, when more experience will be gained.

Acknowledgement

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