

# Aspects and optimization of the mixture for high performance concrete

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**Abstract.** High-performance concrete is currently receiving a lot of attention in research due to its properties and wide range of uses. This paper is focused on HPC, where the optimization of the mixture is specifically addressed regarding the technological solution of construction. The first reference variant uses an approach that is suitable for processing at a concrete plant. An alternative solution is intended for the processing of dry concrete mixture, which can be bagged and the concrete itself produced at the construction site. The paper deals with the comparison of two HPC based on the same input and quantity of raw materials except for the superplasticizer. The purpose is to determine the HPC behaviour and properties of a reference mixture with conventional liquid superplasticizers and a mixture using powdered superplasticizer. The experimental program includes tests of the mechanical properties of compressive strength and flexural strength, where growth was monitored during the first 28 days, split tensile strength and velocity of ultrasound wave. Attention is also paid to fresh mixture tests. Although in the long term the mechanical properties of tested materials were very similar, the difference was determined during the first few days and weeks of hardening, when in mixture using powdered superplasticizer strength characteristics were increasing noticeably slower than in case of referential mixture.

## 1 Introduction

Even today, concrete as a building material does not lose its importance, on the contrary, throughout its existence, new ways are found to improve its properties and use more environmentally friendly input materials. One of the most important shifts in the development of concrete was became existence of High-Performance Concrete (HPC) around the seventies of the 20th century, associated with the development of superplasticizers and very fine mineral admixtures [1, 2], which, in combination with the optimal composition of the binder component and the cement to water ratio, created a stronger and more durable form of concrete [2-4]. All these factors result in a more closed microstructure [5], which directly

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causes a high resistance to carbonation [6], freezing [7], chlorides and sulfates [8, 9]. It is the use of mineral admixtures such as fly ash, slag, finely ground limestone, metakaolin, etc. as additional cementitious materials for partial replacement of cement [10] that can also have positive properties from an ecological point of view [11]. The low cement to water ration of HPC results in a hydration of approximately only 50 to 60% [12], which makes the unhydrated part of the cement suitable for replacement by mineral admixtures. Especially for ecological reasons, today there are generally efforts to reduce the amount of Portland clinker in cement, but one of the efforts is also a complete replacement with an alkali-activated binder system [13, 14]. This paper is intended to show the characteristics of the initial results of testing two selected mixtures and is only the initial step of a more extensive research with the effort to modify the selected mixtures with more environmentally friendly input materials without losing the desired properties. Among the potentially applied admixtures, one can theoretically include finely ground recycled concrete, in which non-hydrated cement grains of the original concrete are revealed, which can subsequently support the hydration of the new concrete [15], as part of the experiment, the possibility of variants with applied fibres [16, 17], usage in 3D printing [18] and design of a mixture with a powder superplasticizer version for the possibility of a bagged concrete mixture are also considered.

## 2 Experimental program

The goal of the displayed paper is to present the resulting mechanical properties of two HPC mixtures. All testing results are available in experimental data set. [19] Both compared mixtures are based on the same input materials and their quantity, with the exception of the plasticizer, where the mixture labeled as REF (Reference mixture) uses a combination of two liquid superplasticizers with the ChrysoFluid Optima 185 (based on polycarboxylate and polyphosphonate) and MasterGlenium ACE 300 PSP mixture with powder superplasticizer (PSP) MELFLUX 1641 F (based on the polymerization product Glycol). Before mixing, a small part (10 kg/m<sup>3</sup>) of the fraction smaller than 0.250 mm from the 0/4 Tovačov sand was removed. The removed amount of fine fraction was subsequently replaced with a dye powder (blue for REF and red for PSP). Both mixtures are shown in detail in Table 1.

**Table 1.** High-performance concrete mixtures.

Input materials	[kg/m <sup>3</sup> ]	
	REF	PSP
Cement CEM I 42,5 R, Hranice	650	650
0/4 – Tovačov	880	880
4/8 – Litice	570	570
Superplasticizer – MasterGlenium ACE 300	20	-
Superplasticizer – Optima 185	10	-
Powder Superplasticizer – MELFLUX	-	19.5
Microsilica, white	70	70
Finely ground limestone	80	80
Water	150	150
Dye powder	10	10

During the mixing of the mixture, the workability of the fresh mixture was determined using the microcone test according to the ČSN EN 1015-3 standard [20] and classification according to TP CBS 07 [21]. The results are shown in Table 2.

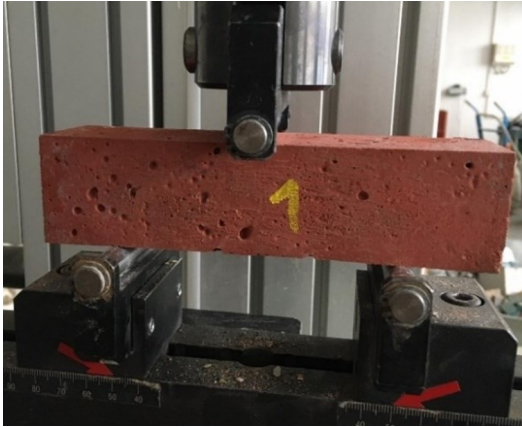
**Table 2.** Results of fresh mixture test.

	<b>Average spill size [mm]</b>	<b>consistency according to TP07</b>	<b>designation</b>
REF	18.5	K3	Thixotropic
PSP	25.5	K2	Viscous

The demoulding of the samples took place 72 hours after mixing in the case of REF. In the case of PSP, the demoulding of the test samples had to be postponed due to the insufficiently solid state of the samples, when the mass was still very soft (reminiscent of plasticine), which can be seen later in the graphs of the dependence of strength properties on time, which were simply not available after 3 days for PSP and were demoulded after 7 days. The REF samples were subsequently placed in a water bath, in the case of PSP it was necessary to choose an alternative. On the previous test samples, it was found that during the first days of curing in the water bath that the surface layer breaks and then separated clusters outside the test samples harden. If the test samples are placed in contact with each other, their connection (adhesion) may occur. This phenomenon occurred because samples were not sufficiently hardened after 3 days since mixing. As an alternative, curing in a climate chamber with 100% humidity was chosen, which at the same time will help to better simulate the environment on the construction site. It is important to mention that for next testing the method of curing samples will be unified, for current comparison could be misleading.

## **2.1 Testing the development of mechanical properties over period of 56 days**

All tested strength characteristics were tested on a laboratory hydraulic press FORM+TEST MEGA 100-300-10DM1 and according to the relevant standards. In the case of testing the development of mechanical characteristics for 56 days, beam-shaped bodies with dimensions of 40x40x160 mm were used, which were tested according to the standards ČSN EN 196-1 Methods of testing cement - Part 1 Determination of strength [22] and ČSN 73 1371 Non-destructive testing of concrete – Method of ultrasonic pulse testing of concrete. [23]. Fig. 1 and 2 show examples of compressive and flexural strength testing.

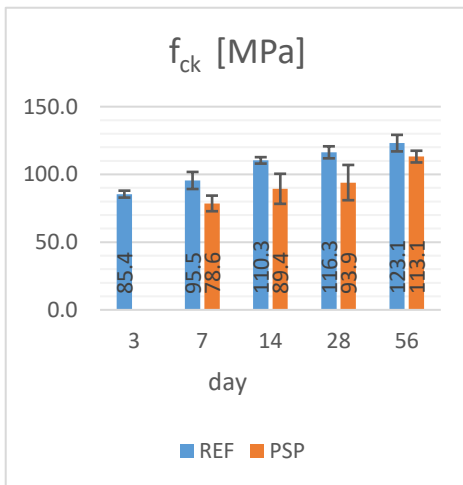


**Fig. 1.** Flexural strength test.

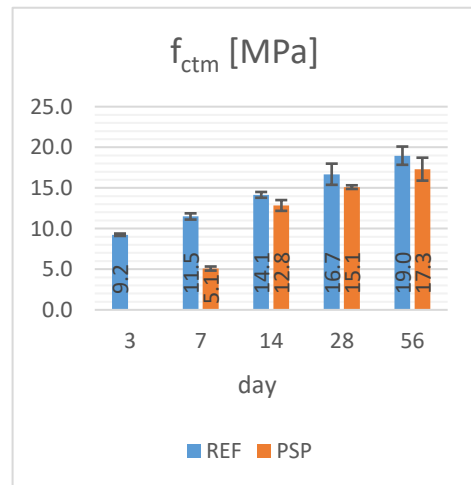


**Fig. 2.** Compressive strength test.

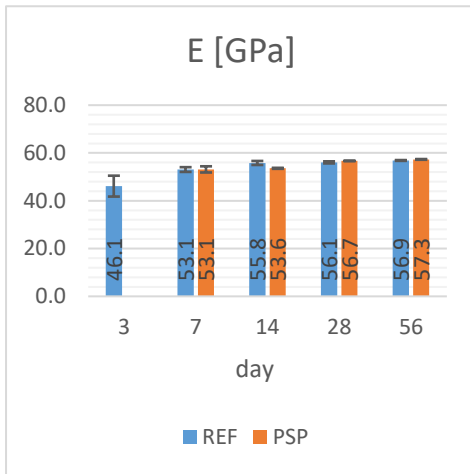
As can be seen from the graph in Fig. 3, the compressive strength of REF HPC was approximately 20 to 23 MPa higher during the first 28 days when compared to PSP. The exception is the strength after 56 days, when PSP continued to increase its strength more significantly and with a final difference of 10 MPa between the compared mixtures. In the case of observing the development of the bending tensile strength (Fig. 4), it was possible to see a slightly different development. The lowest difference (1.3 MPa) between the compared mixtures was in the case of measurements for 14 days. This difference increased during the following weeks up to 1.7 MPa in 56 days. The greatest increase in flexural tensile strength occurred in PSP between days 7 and 14, by 151%. When observing the dynamic modulus of elasticity (Fig. 5), only very small differences were observed between REF and PSP. The lowest value of 46.1 GPa was measured after 3 days at REF. During the following measurements, only minimal changes were detected, when, for example, the difference in REF of the mixture between 7 and 56 days was only 3.8 GPa. A very similar course was also measured for PSP.



**Fig. 3.** Compressive strength for 56 days.



**Fig. 4.** Flexural strength for 56 days.



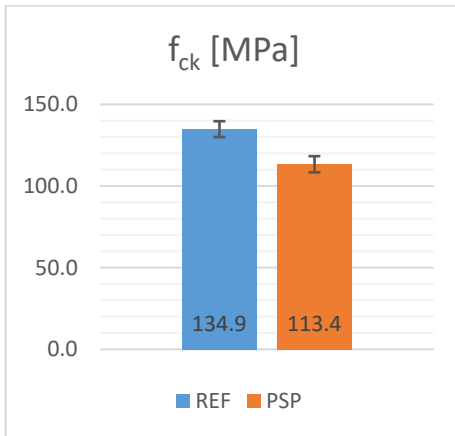
**Fig. 5.** Dynamic modulus of elasticity for 56 days.

Fig. 6 shows structure of the test specimens after the compressive strength test.

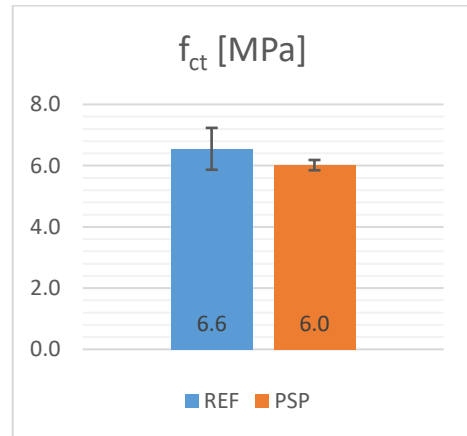


**Fig. 6.** Showcase of samples after compressive strength test (red - REF, blue - PSP).

Greater focus was dedicated for testing strength characteristics (cubic compressive strength and split tensile strength) during the crucial 28 days after mixing. The test was carried out according to the standards ČSN EN 12390-3 Compressive strength of test specimens [24] and ČSN EN 12390-6 Split tensile strength of test specimens [25]. The compressive strength was tested on cube-shaped samples with an edge length of 100 mm and the split tensile strength on cubes with an edge length of 150 mm. Like in the case of the tested beam-shaped samples, the difference between REF and PSP was 23.5 MPa in the case of cubic compressive strengths (Fig. 7). Focusing on split tensile strength (Fig. 8), a 10% difference was observed between 6.6 MPa for the REF mix and 6 MPa for the PSP mix.



**Fig. 7.** 28-day Compressive strength.



**Fig. 8.** 28-day Split tensile strength.

## Conclusion

The performed testing provided an initial insight into the properties of 2 selected mixtures of high-performance concrete. Both mixtures were based on the same input materials except for the superplasticizers used, where REF mixture contains a combination of two liquid superplasticizers and PSP mixture powder superplasticizer. The first difference was already observed during the mixing of the mixture and the workability test. The PSP mixture was determined as more fluid with the viscous category according to TP 07, the REF mixture was determined as thixotropic. Another fundamentally different characteristic was the solidification of the mixture, where with the REF test specimens there was no problem with demoulding already after the first 3 days, while the PSP was still not sufficiently hard. The standard storage of the test bodies in a water bath with the PSP mixture also proved to be problematic when particles were released from the surface of the bodies during the first two weeks. In most tested strength characteristics, REF achieved better results by approximately 9 to 17.7%, with the exception of split tensile strength after the first days of production, when the difference was 151%. An exception can be considered the determined dynamic modulus of elasticity, which was very similar when comparing the two mixtures. As an initial insight into the behaviour of the two designed mixtures, one of which has the potential to become a bagged concrete product intended for quick application on the construction site. The experimental program has the potential to continue on a wider scale, when, apart from expanding the number and types of test bodies and the tests themselves, the plan is also to test the potential application of recycled concrete aggregate as a filler.

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