VERIFICATION OF COMPRESSIVE STRENGTH ON DIFFERENT SIZED HSC SPECIMENS

BÍLÝ Petr [1], FLÁDR Josef [2]

Abstract

HPC and UHPC concretes are getting employed more and more often in civil engineering structures. These concretes are characterized mainly by its high compressive strength. Destructive testing on specimens 150/150/150 mm according to ČSN EN 206 is very demanding with respect to the equipment of the laboratory. To crush UHPC cube with 160 MPa compressive strength, the force of circa 3600 kN is required. The specimens produced sometimes reach 200 MPa strength. In this paper, the results of research focused on determination of compressive strength on HSC cubes of different edge sizes will be presented. The concrete mix tested is called HSC (not HPC), because no properties other than compressive strength were measured. The composition of concrete was intentionally modified to decrease the compressive strength of some specimens under 160 MPa.

Keywords: HPC, HSC, compressive strength

1. Introduction

Concretes with compressive strength higher than 60 MPa ($f_{ck,cube} \geq 60$ MPa) are classified as high-strength concretes (HSC). For production of concretes with strength higher than 100 MPa, the mixture composition and the mixing procedure must be changed substantially. This consequently leads to new physical properties of hardened concretes. Therefore, concretes with high compressive strength and other outstanding properties are referred to as high-performance concretes (HPC).

For concretes of higher class, term „Ultra High Performance Concrete (UHPC)“ is used. Their compressive strength is higher than 150 MPa ($f_{ck,cube} \geq 150$ MPa) and they provide other very high level properties.

The term HPC shows that besides the high compressive strength, these concretes also have other enhanced properties compared to common concretes. Main benefits of HPC are for instance high compressive and tensile strength, low water absorption, high resistance to freeze-and-thaw cyclic loading, long-term stability and durability and rapid reaching of final creep value.

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The title HPC comprises word "concrete". Nevertheless, the material must be understood as a new one and different than other concretes. The differences are given by components used in mixing (namely regarding additives), processing and above mentioned outstanding properties.

Designing of HPC structures is not properly covered by codes and standards so far. The code ČSN EN 1992-1-1 assumes utilisation of concrete with cube strength up to 105 MPa ($f_{ck,cube}$ = 105 MPa). The strength is measured on cubes 150x150x150 mm.

ČSN EN 206-1 [2] mentions concrete with cube strength $f_{ck,cube}$ = 115 MPa; some German codes DIN introduce concrete with cube strength $f_{ck,cube}$ = 120 MPa. Concrete with strength over 160 MPa is not included in any present-day code. Guidelines for preparation of testing specimens for laboratory testing are not given either.

Testing of HPC characteristics on classic cube 150x150x150 mm is not suitable, as for this size of specimen the applied load of compression testing machine must be several thousand kilonewtons. Reaching such values of applied testing load is difficult. Therefore, many laboratories test smaller specimens. Test cubes 100x100x100 mm are most frequently used. The disadvantage of testing the smaller specimens is inaccuracy of test results. If extremely small specimens are used, the laboratory tests can exhibit several times higher strengths. In our research, in both cases (150 mm and 100 mm cubes) aggregate with maximum grain size 16 millimetres was used. This meets the requirement of specimen size being more than three times the maximum grain size.

2. Experiments

Cubes 100x100x100 mm are used for testing of compressive strength in the HPC research program at Faculty of Civil Engineering, Czech Technical University in Prague. Commonly accepted compressive strengths are those measured on specimens with size 150x150x150 mm. Keeping in mind the consequences of size effect, the influence of specimen size on compressive strength had to be verified for correct interpretation of tests conducted on smaller specimens at different levels of compressive strength. The objective was to determine possible relation between specimen size and compressive strength.

2.1 Preparation of specimens

The aim of the experiments was to determine the relation between compressive strengths measured on specimens of different sizes. The composition of the mixture was adjusted to obtain different values of compressive strength. Overview of ranges of mixtures compositions is presented in table 1.

Tab. 1: Composition of mixtures

Compound	Type	Amount	Unit
Cement	CEM I - 42,5	600 – 900	kg/m^3
Water/Binder ratio	-	0.2 – 0.25	-
Aggregate	Quartz 4/8	500 – 1000	kg/m^3
	Quartz 2/4	200 – 400	kg/m^3
	Quartz 0/2	150 – 600	kg/m^3
Plasticizer	Polycarboxylate	10 – 30	kg/m^3
Microfiller	-	20 – 50	kg/m^3
Fibres	Steel	100 – 200	kg/m^3

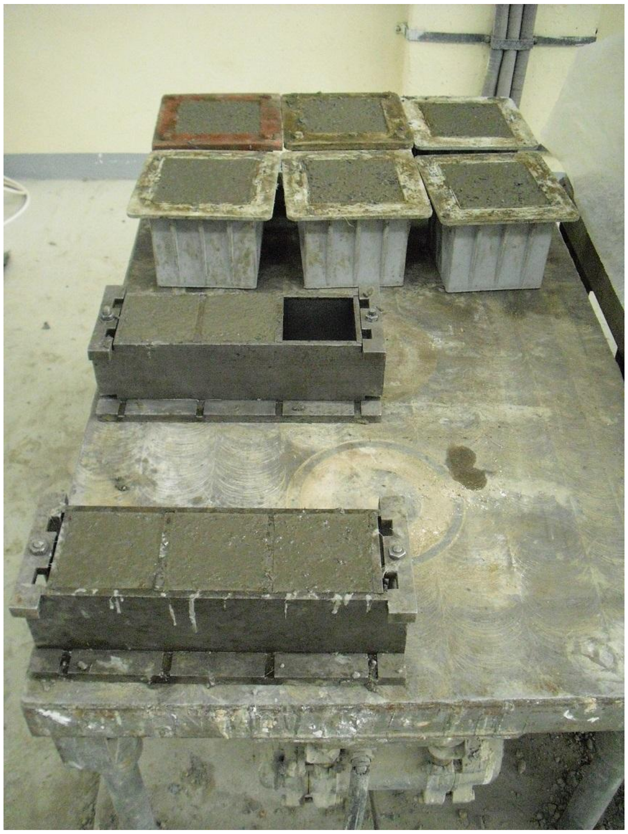

Fig. 2: 150 mm and 100 mm specimens in moulds.

2.2 Curing

Various methods of curing are used in HPC production. To reach compressive strength over 180 MPa, thermal curing of concrete together with moisture or water curing is applied. The test specimens in this experimental program were cured in a water container with temperature of 20 ºC during 26 days.

2.3 Testing

All test specimens were subjected to destructive testing in hydraulic compression testing machine at the age of 28 days. The tests were performed according to ČSN EN 12390-3 [3]. The bulk density was determined before compressive strength tests.

3. Results

The aim of the research was to determine the relation between strength measured on cubes 150x150x150 mm and strength measured on cubes 100x100x100 mm. The main objective of the study was the reduction of costs of HPC research. Testing of smaller specimens decreases the amount of consumed materials. For preparation of the same number of specimens, smaller batch volume has to be mixed.

The main benefit is the decrease of demands on the testing machine. The HPC specimens achieve high compressive strengths. Bigger test specimens require compression testing machine with higher rated load. Destructive testing of smaller specimens is less demanding concerning the compressive load of the testing machine.

Table 2 shows values of compressive strength measured on cubes with size 150x150x150 mm and values measured on cubes 100x100x100 mm. Both sets with different specimen sizes were manufactured based on the same composition and from the same batch. Seven batches (A – G) were mixed. The adjacent columns show compressive strengths of specimens manufactured from the same batch and measured on bigger and smaller test specimens. In the last row, coefficients calculated as ratio of average compressive strengths measured on specimens with size 150x150x150 mm and specimens with size 100x100x100 mm are presented.

Tab. 2: Compressive strength in MPa as measured on cubes 150x150x150 mm and 100x100x100 mm. Overview of all seven different batches.

Batch	**A**		**B**		**C**		**D**		**E**		**F**		**G**	
Specimen size [mm]	***150***	***100***	***150***	***100***	***150***	***100***	***150***	***100***	***150***	***100***	***150***	***100***	***150***	***100***
Specimen 1	101	115	106	121	109	120	133	139	139	146	144	130	178	168
Specimen 2	98	116	102	118	106	124	132	138	144	143	145	152	177	173
Specimen 3	98	115	103	121	118	127	132	137	140	143	129	142	170	191
Specimen 4									143	143				
Specimen 5									143	148				
Specimen 6									143	142				
Average compressive strength	99	116	104	120	111	124	133	138	142	145	139	141	175	177
Coefficient	**0,852**		**0,867**		**0,897**		**0,960**		**0,981**		**0,985**		**0,987**	

The graph (figure 2) shows relation of compressive strength and ratio of compressive strengths measured on cubes 150x150x150 mm and cubes 100x100x100 mm. Increase of the ratio with increasing compressive strength is evident. Using coefficients form the presented plot, the investigation of compressive strength of HPC can be performed with cubes 100x100x100 mm, the results can be easily converted and compared with results for commonly used 150x150x150 mm cubes.

Presented results should be considered as informative, as for different concretes (with different grain-size distribution or different sizes of aggregate) the conversion factors can vary.

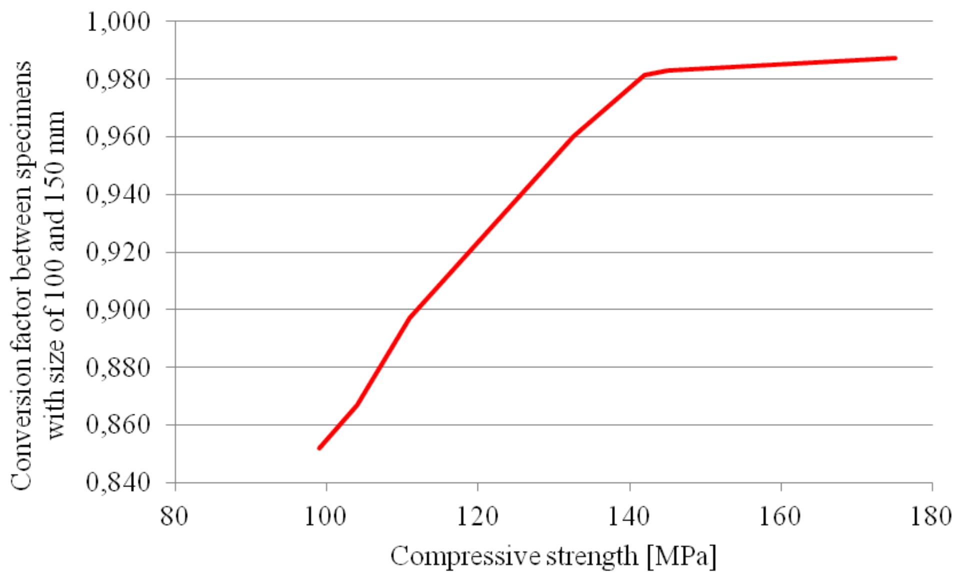

Fig. 2: Relation of compressive strength and conversion factor between compressive strength measured on cubes 150x150x150 mm and cubes 100x100x100 mm

4. Conclusions

The paper presents effect of the size of cube specimen on cube compressive strength. Two specimen sizes were compared – cubes 100x100x100 mm and cubes 150x150x150 mm. The presented graph indicates that the size effect decreases with increasing strength. This corresponds to findings of Kim and Yi [5].

For compressive strengths higher than 140 MPa, the graph also shows a value of conversion factor 0.98 for the relation between strength determined on cubes 100x100x100 mm and cubes 150x150x150 mm. This value was determined from relatively small set of experimental results. For objective analysis of compressive strengths of various concrete samples, it should be reduced with respect to reliability and uncertainties in composition of mixtures different from tested ones.

Conclusions of this paper are important for testing of HPC specimens, as they indicate that by using appropriate conversion factors, standard cubes 150x150x150 mm can be replaced by smaller cubes 100x100x100 mm without unwanted effect on the results.

In further work, authors would like to focus on theoretical explanation of size effect impacts on testing of HPC properties. This will probably require some additional experimental work to obtain more representative set of data.

Within the scope of research program, cubes with dimensions smaller than 100 mm were tested. The results had high scatter, the accuracy was not sufficient. Therefore, the authors do not recommend using smaller specimens for HPC compressive strengths testing.

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