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Comparison of Properties of Shotcrete Tested Using Destructive and Non-destructive Methods

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Abstract

The paper focuses on possibilities of preparation and observation of basic physical parameters of shotcrete prepared in ordinary laboratory mixer, compacted by vibration combined with defined pressure. The aim is assessment of basic properties of shotcrete: compressive strength of young shotcrete, test core strengths and comparison of results with the results of non-destructive tests of compressive strength. At the same time, homogeneity and consistency of shotcrete will be assessed.

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1. Introduction

Shotcrete (sprayed concrete) is applied mainly for construction of tunnels, shafts, renovation works and strengthening of slopes. Main advantage of shotcrete is fast development of strength, which quickly ensures stability of strengthened structure. Spraying of concrete ensures perfect fastening of concrete to base material, filling all cavities, cracks and pits and thanks to almost immediate hardening, no formwork is needed.

Sprayed concrete is different from standard compacted concrete not only as regards composition of the mix but also as regards application of the structure. There are two commonly used methods of application shotcrete. Both

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methods drive mix in the apparatus by means of compressed air. Then, the mix is transported to spraying nozzle through a pipe or a hose. Both methods differ in the stage, where mixing water is added. Both methods have advantages and disadvantages. Selection of one of the methods depends on the character of construction. Currently, mainly the wet technology is applied particularly for the reason of better homogenization of the mix, higher quality of the coat and higher performance of the method. Compared to dry spraying, the wet technology is usually 4-5 times more efficient. In general, it can be said that wet technology is used for large-scale construction while dry spraying is used for renovation works and smaller constructions [5, 6].

In building industry, non-destructive methods are used particularly for determination of properties of concrete on constructions (mainly compressive strength) For concrete, the most used method is rebound hardness meter (Schmidt system hardness meters) and ultrasonic pulse method - test methods are codified in international and national standards, for example ISO 1920-7 [11], CSN 731373 [8]. Non-destructive methods are used also for determination of strengths of other material, for example Brožovsky et al. tested bricks [1,2], concrete paving blocks [3] or cement [4].

2. Properties of shotcrete

For definition of sprayed concrete, it is important to realize that shotcrete differs from commonly compacted concrete by the technology of application on base material. Even though composition corresponds to common compacted concrete, properties begin to differ after application by spraying. Shotcrete differs not only by strength, which is influenced mainly by addition of accelerators but also water-tightness, frost resistance and durability of shotcrete. After spraying concrete onto base material, porous structure of concrete changes, a part of the material falls off which increases content of fine parts, which can cause higher values of shrinking. All these has to be taken into account when designing structures from shotcrete.

One of the main observed properties is development of compressive strength within the first 24 hours after application. This value is determined in accordance with CSN EN 14488-2 [12] with penetration needle and consequently by the method of shooting nails. However, both methods provide only informative values of strength on the basis of calculation according to calibration curves. The advantage of these methods is that they can be used in situ. The method of penetrating needle determines strengths from 0.2 N/mm^2 to 1.2 N/mm^2. For strengths from 1.0 N/mm^2 to 16 N/mm^2 the method of shooting nails is used. Real values of strength are then determined on cores drilled from the construction or from testing slabs [12].

Compressive strength of commonly compacted concrete is measured on testing specimens (usually cubes with side 150 mm) made from tested concrete. Test cubes are loaded up to the failure limit in a test press. However, it is not so simple to determine strength of sprayed concrete. Shotcrete cannot be sprayed into cube forms because counter pressure of the form causes segregation of concrete mix. Coarse fractions then gather in corners of the form, fine fractions and cement are removed from the form.

In practice, spraying concrete into test boxes with dimensions 500 x 500 x 200 mm is used. Size of such a box is large enough to prevent above-mentioned problems of 150 mm cube form. Test cubes can be cut from these concrete blocks or a test core can be drilled. Test cores can also be drilled directly from the construction [5].

3. Laboratory preparation of shotcrete

Designing concrete mix, its preparation and testing is quite complicated nowadays. Since machinery has to be used for spraying, it is also costly. For this reason, there are efforts to formulate correlations, which could predict strength of shotcrete on the basis of development of strength of shotcrete prepared in laboratory. Concrete prepared in laboratory has the same composition as concrete applied on the construction; application by spraying is simulated by compacting concrete placed into a form by pressure board with defined pressure.

Tested concrete was made from Portland cement CEM I 42.5 R, plant Mokrá, combined with plasticizer SIKA Viscocrete 2700 and setting accelerator for shotcrete SIKA Sigunit L 53 AF. Dosage of accelerator was 4%, 6% and 8% by the amount of cement used. Aggregate used was of size fractions 0-4 washed from Zabcice, coarse crushed 4-8 from Olbramovice. To increase fine parts in concrete, fly ash from Detmarovice was used in the amount of 50kg. In the first stage, tests of shotcrete applied by spraying machine were carried out. To observe properties, testing blocks with dimensions 500 x 500 x 150 mm were manufactured. For laboratory mixing, these forms were also used with compacting on vibration table with pressure board and pressure 250 kg/m^2.

4. Young shotcrete

Following table gives test results of young shotcrete. The test was carried out in accordance with CSN EN 14488-2 [12].

Table 1 Compressive strength of young shotcrete

Penetration needle average values [N/mm^2]							
Time of testing	*Shotcrete 4%*	*Shotcrete 6%*	*Shotcrete 8%*	*Time of testing*	*Shotcrete 4%*	*Shotcrete 6%*	*Shotcrete 8%*
3 min.	0.12	0.13	0.32	60min	0.28	0.36	0.51
6	0.13	0.14	0.37	90	0.42	0.52	0.64
15	0.17	0.17	0.41	120	0.49	0.68	0.85
30	0.20	0.26	0.45	180	0.75	-	-
HILTI-Tester average values [N/mm^2]							
Time of testing	*Shotcrete 4%*	*Shotcrete 6%*	*Shotcrete 8%*	*Time of testing*	*Shotcrete 4%*	*Shotcrete 6%*	*Shotcrete 8%*
3hrs	-	1.1	1.4	9	9.5	10.1	13.2
6	3.8	5.4	6.9	24	16.9	17.3	18.2

5. Non-destructive tests of shotcrete

For non-destructive test of shotcrete, rebound method was used (Schmidt rebound hammer type N) and ultrasonic pulse method. Measurements were carried out on concrete blocks with dimensions 500 x 300 x 150 mm and on core drills at the age of concrete 3, 7, 14 and 28 days. Concrete blocks were placed in standardized conditions in accordance with CSN EN 12390-2 [9] until the time or testing, int. al. to ensure stable value of humidity for reasons of measuring by means of ultrasonic pulse method.

5.1. Test equipment and methodology

The Schmidt rebound hammer, model N: impact energy of 2.207 N.m; is designed for compression strength measuring in the range of 10 – 70 MPa; it as a device, suitable for testing of structures with thickness of 100 mm as a minimum. Each testing slab was divided into 6 testing areas, 6 measurements of rebound values were carried out on each of the 6 areas. During taking measurements, the concrete block was placed in testing press and loaded with force equal to 10% of estimated compressive strength. Direction of testing - horizontal. Average of measured values was calculated; values different by more than ± 15% were excluded. Results of measurements on the concrete block are considered usable for further evaluation if at least 30 valid measurements remain after excluding outliers.

Ultrasonic pulse method: ultrasonic apparatus TICO with accuracy 0.1 μs. Natural frequency probes is 82 kHz. Measurements were carried out by direct and surface sounding. Direct sounding was carried out through the thickness of the test concrete block at 8 evenly distributed measuring points. Surface sounding was carried out on the top facial surface leveled by grinding to reach good acoustic coupling; the area was divided into 6 subareas, distance between probes was 170 mm. Measurement determined time of passage of ultrasonic pulse through concrete; velocity of propagation of ultrasonic pulse was calculated according to the formula (1):

$$V = L/T \qquad (1)$$

Note: V-ultrasonic pulse velocity [km/s], L-length of measuring base [mm], T-transit time [μs].

Compressive strength of test cores: Two test cores with diameter 100 mm were drilled from each block and cylindrical test specimens with ration height: diameter 1:1 were prepared for destructive tests to determine compressive strength (in accordance with CSN EN 12504-1[10], compressive strength of such test specimen is the same as cube strength of concrete).

5.2. Test results and discussion

Table 2 below shows results of tests of shotcrete by both non-destructive and destructive tests.

Table 2. Tests results of shotcrete

Labeling of concrete	*Age of concrete*	V_{DT} [km/s]	*VAR* [%]	V_{ST} [km/s]	*VAR* [%]	*R* [-]	*VAR* [%]	$f_{c,cu}$ [MPa]
SHOTCRETE 4%	3 days	3.832	1.9	3.036	13.0	36.2	5.7	27.5
	7 days	4.047	2.0	3.380	15.0	40.6	6.5	32.1
	14 days	4.051	2.9	3.140	15.7	41.2	5.3	36.1
	28 days	4.058	2.1	3.075	20.7	42.6	6.0	40.1
SHOTCRETE 6%	3 days	3.886	1.6	3.901	3.5	42.7	5.2	33.3
	7 days	3.994	1.9	3.974	4.3	46.0	4.7	43.1
	14 days	4.057	1.6	3.889	4.4	48.4	5.4	48.8
	28 days	4.082	1.6	3.999	6.0	48.7	4.4	50.7
SHOTCRETE 8%	3 days	3.602	2.3	3.211	14.8	32.8	5.5	19.9
	7 days	3.698	2.5	3.427	12.0	37.2	5.7	28.2
	14 days	3.749	2.6	3.387	12.0	39.3	6.2	32.2
	28 days	3.772	2.1	3.352	10.2	42.7	6.0	33.1

Note: Average values V_{DT}-ultrasonic pulse velocity z direct transmission, V_{DT}-ultrasonic pulse velocity z surface transmission, R-reboud number, $f_{c,cu}$- cube strength, VAR-variation coefficient.

To assess usability of mentioned non-destructive methods for determination of compressive strength of hardened shotcrete, spread of measurement results for given test method was evaluated (variation coefficient of observed parameter was criterion), correlations between parameter of non-destructive testing and compressive strength were elaborated, comparison of values of compressive strength obtained through elaborated correlations and correlations for normal-weight concrete stated in CSN 737371 [7] (ultrasonic pulse method) and CSN 731373[8] (Schmidt rebound hammer type N) were compared.

Variability of parameter from non-destructive tests. Variability of rebound value of Schmidt hammer (4.4 to 5.5%), and velocity of propagation of ultrasonic pulse during direct sounding (1.6 to 2.9) is within limits from the point of practical usability of given non-destructive method of testing shotcrete with ultrasonic pulse and direct sounding.

Variability of propagation velocity of surface sounding is considerably high (3.5 to 20.7%). Ultrasonic waves go under surface of testing material during surface sounding and they are considerably influenced by condition of surface layer of concrete. Surface sounding of sprayed concrete built in constructions seems inapplicable.

Correlations between parameter from non-destructive test and compressive strength of shotcrete. Based on test results, correlation (2) between value of rebound and compressive strength (Schmidt rebound hammer type N) and correlation (3) between velocity of propagation of ultrasonic pulse and compressive strength (ultrasonic pulse method, direct sounding).

Schmidt rebound hammer, model N

$$f_c = 1.8032R - 39.824 \tag{2}$$

Ultrasonic pulse method-direct transmission

$$f_{ce} = 276.47V_{DT} - 28.002V_{DT}^2 - 617.58 \tag{3}$$

Elaborated correlations show high matching of variables, correlation coefficient for Schmidt rebound hammer type N is 0.95, for ultrasonic pulse method and direct sounding the value is 0.91.

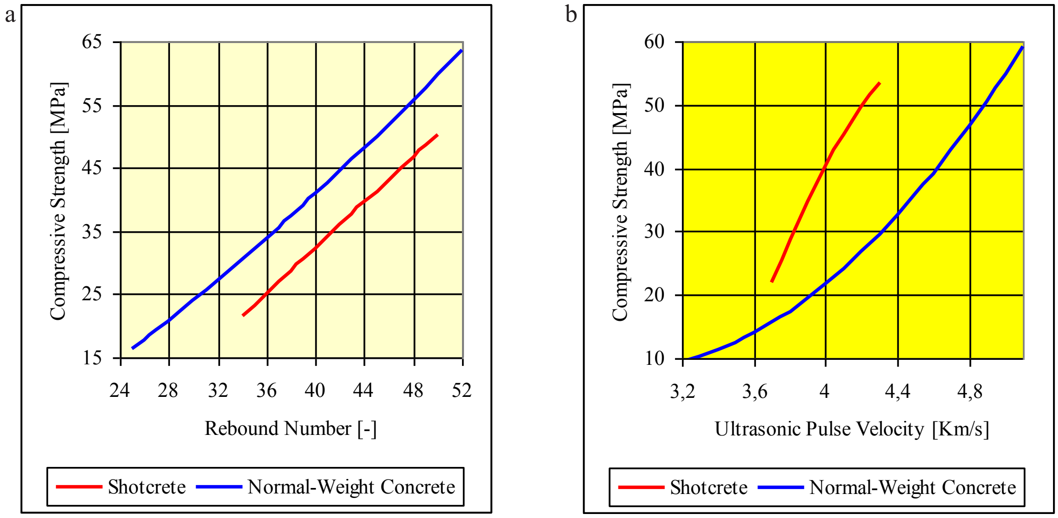
Comparison of correlations elaborated for shotcrete with calibration relations for normal-weight concrete [7, 8]. Standards [7, 8] state calibration relations (4 and 5) for normal-weight concrete with natural aggregate, age of concrete 14-56 days, processed with common technologies. Comparison of calibration relations for normal-weight concrete with relations elaborated for shotcrete is illustrated in Figure 1

Schmidt rebound hammer, model N

$$f_{ce} = 0.0095R^2 + 1.0046R - 14.998 \quad (4)$$

Ultrasonic pulse method-direct transmission

$$f_{ce} = 9.9V_{DT}^2 - 56V_{DT} + 87.3 \quad (5)$$



Schmidt rebound hammer, model N

Ultrasonic pulse method-direct transmission

Fig. 1. Comparison of Compression Strength Values with with standard calibration relationships (a). (b).

Comparison shows that use of standardized calibration relations (4 and 5) for prediction of strength of shotcrete from the value of rebound or velocity of propagation of ultrasonic pulse is contentious. Values of strength are considerably over-valuated for Schmidt rebound hammer and under-valuated for ultrasonic pulse method.

6. Conclusion

The paper focuses on problems of laboratory preparation and testing shotcrete. Values of strength obtained through destructive and non-destructive methods were compared. Usability of non-destructive test methods for evaluation of compressive strength of shotcrete was proved. Schmidt rebound hammer is practically usable for evaluation of shotcrete, however, only if calibration relation is elaborated on the basis of such extent of tests that reproducibility of test results is assured. Use of ultrasonic pulse method is limited by the method of sounding (direct sounding), which can be use only on test specimen taken from the construction.

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