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Gypsum Free Cements and Concretes Made with Them: Strength Determination Using Nondestructive Testing Methods

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Abstract

Gypsum free cement (GFC) is based on Portland clinker. Gypsum as an initial setting time regulation additive is replaced by a system based on lignosulfonane of alkali metal and carbonate of alkali metal. This binder features high initial strength and short initial setting time; subsequently, these properties continue in concretes made with this binding material. Concrete with gypsum-free cement is characterized with short setting time and high initial strength. Concrete with gypsum-free cement has comparable strength after 3 days of curing with a 28 days strength of common concrete with Portland cement containing gypsum. Our paper describes methodology and calibration relations for both – GFC strength determination through ultrasonic pulse velocity and strength determination of types of concrete made with GFC using ball thrust hardness test. The last-named method is applicable for GFC compression strength determination; and also for types concrete based on GFC, commendable are impact hammers (Schmidt Impact Hammers type N and/or L respectively – made by PROCEQ Co., Switzerland). These methods enable testing of concretes based on GFC after their casting without any harm to materials built into construction in contrast to destructive strength tests on cores. Presented testing methodology along with test results take into account specificity of particular materials and products. As analyzed above, this methodology is usable in technical practice. The methodology constitutes essential precondition of measurement reproducibility and repeatability.

1. Introduction

Concretes containing gypsum free cements (GFC-C) are distinguished by rapid strength increase in aging of 1 or 3 days. This feature predetermines them for using in repairs of structures to be put into service as soon as possible. One of the fields for utilization thereof is repair of cement-concrete roadway wearing courses or surface repairs of similar character. When preparing GFC-C, it is necessary to bear in mind features and strength parameters of the used cement as well as the strength features of hardened concrete already built in the structure, especially the data of compression strength. In non-destructive testing of concrete, the hardness testing method is prevailing, whereas ultrasonic pulse method is applicable under certain circumstances. The testing procedures are specified in standards, such as CSN EN 12404 –2 or CSN EN 15204-4. These standards, however, do not contain any calibration relations necessary for concrete strength determination with reference to non-destructive testing methods. Even the description of hardness test methods in ČSN 73 1373 standard is not reliable for determination of hardness relations, as those hardness tests are based on strength determining of current concretes in aging of 14 – 56 days, which evokes a question, how concretes with high initial strength values may be utilized.
The standards for cement testing a priori do not reckon with possibilities of strength detecting by using of non-destructive methods, even if such methods may lead to a certain rationalization and limitation of specimen test piece number.
The paper contains utilization solutions resulting from parameters of compression strength determined by non-destructive testing methods. The concretely applied methods were: hardness and hardness drop tests by Schmidt machine (for concrete testing) and ultrasonic pulse method (for cement testing). There exist also respective calibration relations pertaining to these methods. The calibration relations were processed by the method of minor squares and the utility thereof was measured on the base of correlation coefficient value, equalling to at least 0.85 or better to more than 0.9 for practically usable calibration relations.

2. Gypsum free cements and concretes

Gypsum free cement (GFC) is a binding agent based on fine ground Portland clinker (with specific surface exceeding 450 m^2/kg), in which gypsum admixture regulating initial point of setting is replaced by a lignosulphonate system of alkaline metal and carbonate of an alkali metal. Such cements are distinguished by high initial strength values. Some types of gypsum free cements were produced subsequently in the Czech Republic, namely:

Modified quick-binding high strength cement (MRVC)
quick-binding cement lute (RVCT)
NOYEMENT
Gypsum free quick-binding high strength cement (BSRVC)
quick-setting high strength cement (BS55c)

The basic physical and mechanical characteristics thereof are shown in Table 1 below.

Table 1. Basic Physical and Mechanical Characteristics of Gypsum Free Cements

Binder		**MRVC=NOYEMENT**		**RVCT**	**BS RVC**	**BS55h**
		II	**III**			
Specific Surface	[m²/kg]	500 -700	700 -900	>550	365	470
Initial Point of Setting	[min]	3	3	20	25	20
Period of Setting	[min]	120	120	90	90	180
Compression Strength as a Minimum [N.mm^{-2}]	4 h	2-5	6-10	--	2.0	--
	24 h	30-40	30-50	30	35	35
	3 days	45-50	60	45	45	42
	7 days	50-60	70	--	--	--
	28 days	50-70	90	55	55	55

Concretes containing gypsum free cement are composites with high initial strength values (in aging of 1 to 3 days, showing compression strength values between 20 and 55 MPa in dependence on water ratio and cement strength values) and with short point of setting (25 to 60 minutes). The said features of gypsum free concretes are connected with features of the used cement types.

3. Ultrasonic Pulse Method as Compression Strength Determiner in GFC

Measuring of ultrasonic pulse velocity is influenced by many a factors, especially by material moistness, shape of testing specimen, component features and probe frequency. When testing cement compression strength, the specimen must have an accurately defined shape, the cement mortar must have expressly defined ratio of cement and gravel (CSN EN 196-1), water ratio for GFC is 0.31-0.33 (differentiation against CSN EN 196-1, determining mortar water ratio of 0.50). Test specimens are before testing stored in water bath in order to ensure constant moisture conditions. Frequency of probes is very important. As to the building materials, frequency of probes between 40 and 150 kHz is suitable. An optimal state is, when wave-length of ultrasonic undulation enables measuring in one-dimensional or three-dimensional environs. Dimension of environs depends on dimensions of test specimens and on wave-length of ultrasonic undulation. Standard dimension of concrete specimen for testing of strength values is 40 x 40 x 160 mm, which does not enable to secure measuring in environs above, so that using of probes with constant frequencies is unavoidable.

3.1. Requirements for Testing Equipment and Specimens, Measuring Procedure

Testing equipment – must fulfil demands of CSN EN 12504–4. Probes with frequency of 82 – 100 kHz are used for measuring.
Specimens: surface to be detected with probes must be smooth and clean.
Measuring procedure: Wet specimens are measured immediately after taking out from water bath. Transit time measuring follows by direct sonic test over the whole specimen – see Fig. No.1. To achieve perfect acoustic feedback, a suitable binding agent (e.g. sonogel as used in medicine) should be applied on probes and specimen. Transit time measuring of each specimen is done three times. In case, the results do not

differ from the smallest measured value by more than 5 %, an average is calculated thereof (modified method according to ČSN 73 1371). After the completed transit time measuring the length of measuring base is determined with accuracy of 0.1 mm. These values are input parameters for calculation of ultrasonic pulse velocity. Ultrasonic pulse velocity is calculated from relation 1 stated in EN 1504-2,

$$V = \frac{L}{T} \qquad (1)$$

where:
V ultrasonic pulse velocity [m/s or km/s]
L length of measuring base [m]
T transit time [s]

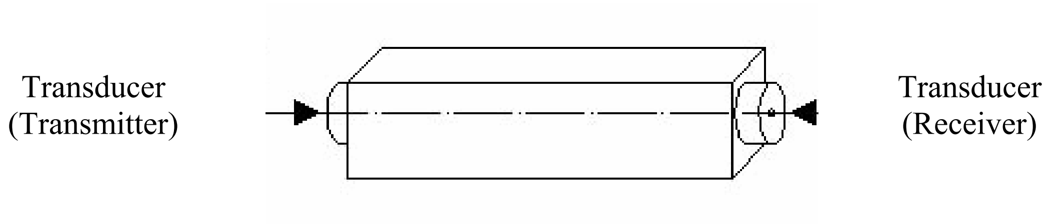

Figure 1. Scheme of Direct Transmission

Compression strength was measured by destructive method after the accomplished non-destructive measuring according to CSN EN 196-1. Calculation thereof follows from relation 2,

$$f_{pd} = \frac{F}{1600} \qquad (2)$$

where:
f_{pd} – compressive strength [MPa]
F – destruction force [N]
1600 – pressure surface [mm^2]

3.2. Results of Measuring

Totally 583 specimens were tested (335 MRVC and RVCT and 248 NOYEMENT, BSRVSC and BS 55h). All measuring results inclusively relations depending on ultrasonic pulse velocity and compression strength are shown in diagram, Fig. 2.

4. Non-destructive Testing of Concrete Containing Gypsum Free Cement by Hardness Drop Tester System, Type Schmidt N / L

4.1. Requirements for Testing Equipment and Specimens, Measuring Procedure

Method of hardness drop testing proceeds from knowledge of concrete flexibility depending on its strength. Upon testing, hammer falling down to specimen surface moves in free fall or by means of spring energy, whereas rebound intensity is measured. Schmidt machines differ from type to type by hammer blow energy amounting to 2.207

Nm in case of N-type and to 0.735 Nm in case of L-type. Schmidt machine system is shown in Fig. 3.

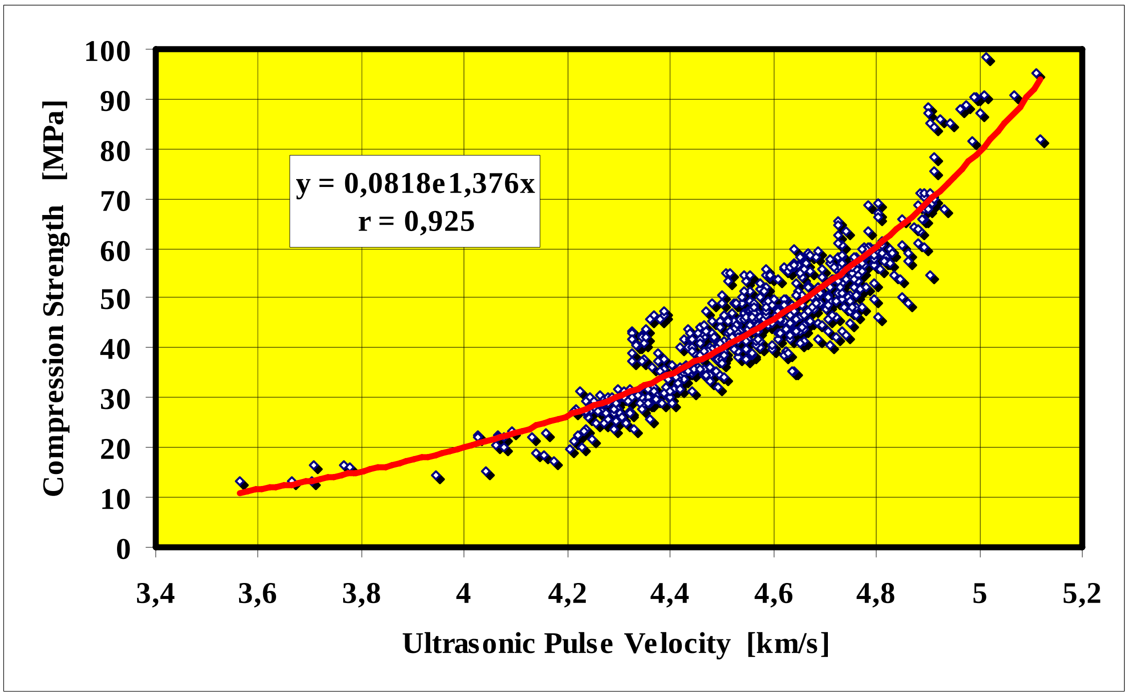

Figure 2. Test Results. Measuring of Relations Depending on Ultrasonic Pulse Velocity and Compression Strength on Gypsum Free Cements

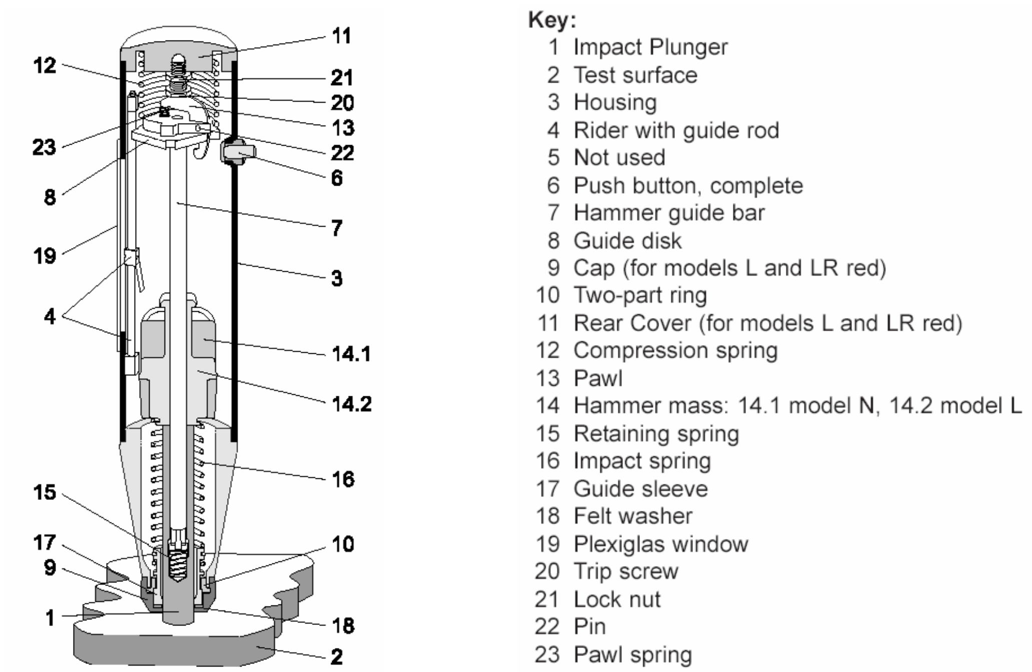

Figure 3. Description of Concrete Test Hammer Schmidt, Types N / L (source: www.proceq.com)

Testing equipment must fulfil demands of EN 12504 – 2.

Specimens: tests were done with concrete specimens, dimensions 150 x 150 x 150 mm.

Measuring procedure: a specimen placed in testing press is exposed to force representing 10 % of expected concrete strength. Then, rebound measuring by Schmidt hammer follows 10 times on surface of each opposite side. Measuring conditions must be in conformity with CSN EN 12504-2. Complex of 20 measured rebound values serves for calculation of average, whereas rebound values differing from the average by more than 12.5 % are excluded. If less than 16 values remain after the exclusion, such specimen is replaced by another one for new testing.

Compression strength – non-destructive measuring was followed by destructive method, assessed according to EN CSN 12390-3.

4.2. Measuring Results

Totally 320 specimens containing different types of gypsum free cement were tested. The test results including relations depending on hardness tester rebound and compression strength are shown in diagrams, Fig. 4 and 5.

5. Calibration Relations

This paragraph describes calibration relations based on destructive and non-destructive tests made with individually examined materials.

5.1. Gypsum Free Cements

Relation 3 for GFC compression strength under consideration of ultrasonic pulse velocity was calculated as follows:

$$f_{c,CEM} = 0{,}0818^{1{,}376V} \qquad (3)$$

r = 0.925 V 3.5 ; 5.2 [km/s], aging of specimens between 1 and 365 days, n = 583.

5.2. Concretes Containing Gypsum Free Cements

Following calibration relations (4a-4c) and (5a-5c) were elaborated for determining the concrete compression strength resulting from rebound values detected by Schmidt hammer:

Schmidt hammer, type N :

$$f_{ce} = 0{,}1429 R_N^{1{,}5457} \qquad (4a)$$

r = 0.914 R 21; 49 , concrete aging between 1 and 3 days.

$$f_{ce} = 0{,}1832 R_N^{1{,}4746} \qquad (4b)$$

r = 0.921 R 21; 51, concrete aging between 1 and 7 days.

$$f_{ce} = 0{,}2377 R_N^{1{,}4006} \qquad (4c)$$

r = 0.927 R 21; 58 , concrete aging between 1 and 28 days.

Schmidt hammer, Type L

$$f_{ce} = 1{,}2699 R_L^{0{,}9907} \text{ ....(5a)}$$

r = 0.882 R 16; 45 , concrete aging between 1 and 3 days

$$f_{ce} = 1{,}3676 R_L^{0{,}9686} \text{ ....(5b)}$$

r = 0.900 R 16; 50 , concrete aging between 1 and 7 days.

$$f_{ce} = 1{,}3307 R_L^{0{,}977} \text{ ....(5c)}$$

r = 0.914 R 16; 54 , concrete aging between 1 and 28 days.

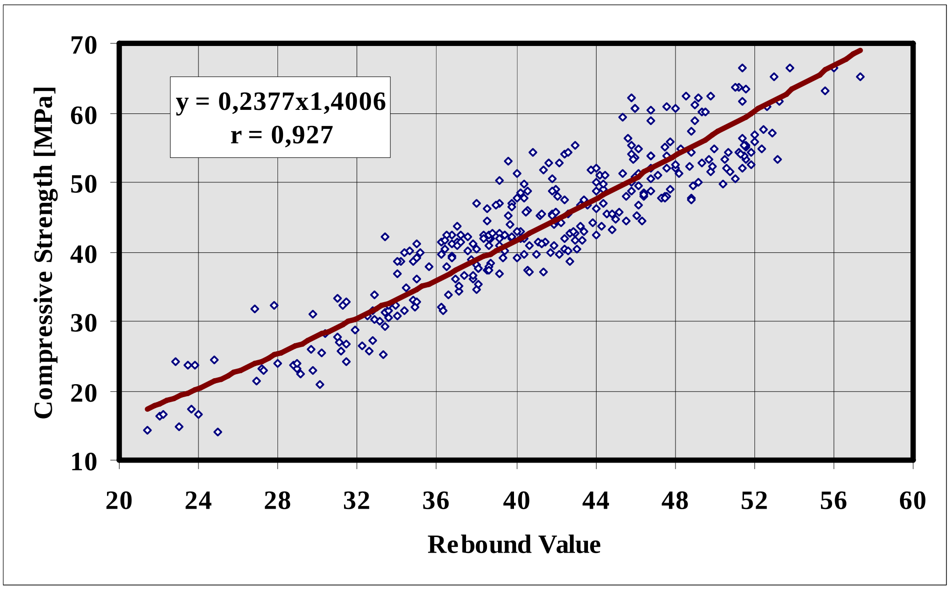

Figure 4. GFC-C Test Results, Dependency on Relation between N-Type of Schmidt Hammer Rebound Value and Compression Strength

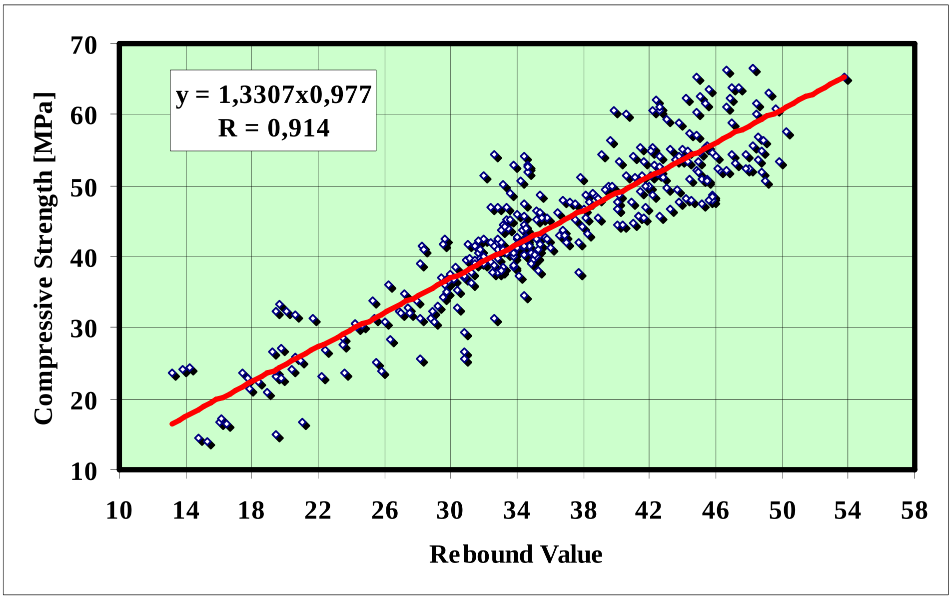

Figure 5. GFC-C Test Results, Dependency on Relation between L-Type of Schmidt Hammer Rebound Value and Compression Strength

6. Conclusion

6.1. Gypsum Free Cements

Presented trials have proved practical utility of ultrasonic pulse method for determining of compression strength with gypsum free cements under unambiguously defined measuring conditions. The calibration relation elaborated for determining of compression strength based on ultrasonic pulse velocity shows a high feedback in relation between variables; correlation coefficient r = 0.925 may be used in practice.

Methodology of testing and result assessment is utilizable without any problems, however, it requires strict meeting of measuring conditions, especially regarding invariable moisture state of test pieces which, under no circumstances may not be dried, as changing of moisture conditions influences values of ultrasonic pulse velocity (ultrasonic pulse velocity in water triplicates the same in the air).

Another important factor influencing measuring results is the actuator frequency, as currently used probes (40 to 100 kHz) do not ensure suitable conditions for measuring in one-dimensional or three-dimensional environs in the sense of ČSN 73 1371, Art. 24. The given instruction reckons with actuator of frequency between 80 and 100 kHz. Any usage of actuator with different frequency requires verification as per the ČSN 73 1370 determining decisive residual deviations to be discovered by the method of ČSN 73 1370 (6 test pieces in 3 aging periods as a minimum). In the event of residual deviation exceeding 0.12, a précising coefficient is to be determined by means of destructive and non-destructive tests in accordance with ČSN 73 1370.

Indifferent gel utilized in medicine works well as binding agent securing good acoustic feedback, when applied on probes and specimens. It is advisable to use the same gel type for testing of a specimen set. A new device calibration is necessary before using another binding agent.

6.2.Concretes Containing Gypsum Free Cements

On the base of test results, calibration relations for compression strength determining with concretes containing gypsum free cement were elaborated, showing correlation coefficient between 0.914 and 0.927 for Schmidt hammer type N and correlation coefficient between 0.882 and 0.914 for Schmidt hammer type L.

In case of built in concretes containing gypsum free cement, it is very important to know compression strength values in aging of less than 3 eventually 7 days and in this respect, Schmidt hammer type N is more suitable for non-destructive testing.

The mentioned testing methodology inclusively the way of resuming and assessment of results is utilizable in practise. The concrete surface to be tested by hardness drop tester is to grind off before in order to secure reproducibility of test results.

Acknowledgements

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