SCIENTIFIC
AND DIDACTIC EQUIPMENT

Concrete shrinkage test methods used in engineering practice

KAJA KŁOS[1], GRZEGORZ ADAMCZEWSKI[2]
[1] TPA SP. Z O.O., [2]WARSAW UNIVERSITY OF TECHNOLOGY, DEPARTMENT OF CIVIL ENGINEERING

Keywords: concrete technology, concrete shrinkage, concrete shrinkage measurement methods.

ABSTRACT:

Designing the composition of a concrete mix is a technically complex issue and requires not only the direct conditions of the concrete use to be considered, but also, in particular, the rheological characteristics of concrete to be examined in the context of the anticipated conditions of concreting and maturation conditions under actual construction site conditions. The article discusses the phenomenon of concrete shrinkage and the factors affecting its intensity. It also presents a description of individual concrete shrinkage test methods which are most commonly used in engineering practice.

Metodyka badań skurczu betonu stosowana w praktyce inżynierskiej

Słowa kluczowe: technologia betonu, skurcz betonu, metody pomiaru skurczu betonu

STRESZCZENIE:

Projektowanie składu mieszanki betonowej jest zagadnieniem skomplikowanym technicznie i wymaga uwzględnienia nie tylko bezpośrednich warunków eksploatacji betonu, ale także w szczególności zbadania charakterystyki reologicznej betonu w kontekście przewidywanych warunków betonowania oraz dojrzewania w rzeczywistych warunkach budowy. W artykule omówiono zjawisko skurczu betonu oraz czynniki wpływające na jego intensywność, przedstawiono także opis poszczególnych metod badawczych skurczu betonu najpowszechniej stosowanych w praktyce inżynierskiej.

1. CONCRETE SHRINKAGE PHENOMENON

Ensuring the durability of concrete is a key issue in terms of maintaining the required performance of the structure and optimisation of its operating costs. In the process of designing and erecting concrete structures, a frequent error is to omit or trifle with the problems pertaining to the construction technology – this applies in particular to the aspects of concrete rheology.

Concrete shrinkage is a rheological process which is extremely undesirable and impossible to eliminate due to its intrinsic nature. It causes stresses (often unevenly distributed) or deformations and may lead to loss of monolithic performance of the structure, decrease of its durability and accelerated degradation. This involves the need to perform expensive repairs and protections, and in extreme cases even the demolition of the structure. A complete elimination of the concrete shrinkage phenomenon is not possible – from a technical perspective it is only possible to minimise its extent and delay its time of occurrence [1]. Factors affecting the intensity of concrete shrinkage are: composition and properties of the concrete mix, reactions in the paste, temperature differences due to the release of heat of hydration, shape and size of the concrete structure and, in particular, conditions of the concrete maturing including weather conditions and the method of concrete curing [2].

Due to the importance of the shrinkage phenomenon for concrete, actions are taken at the design stage to limit its impact, in particular by taking due account of:

- type and content of the basic components of the concrete mix (type of cement and aggregate, maximum size of aggregate grains, D_{max});
- type and content of admixtures and additives;
- water/cement (w/c) indicator values;
- paste content in the concrete mix;
- concrete classes;
- dimensions and geometry of the concrete structure/component;
- conditions for the maturation and curing of concrete. Determination of shrinkage in concrete requires verification of the course of this phenomenon over time using laboratory testing methods and calculation or specialist measurement methods under actual conditions at the construction site.

2. SELECTED CONCRETE SHRINKAGE TEST METHODS

In the last few decades, a number of concrete shrinkage testing methods have been developed using which the intensity and the range of values of this phenomenon in individual concretes can be determined. Unfortunately, the applicable version of PN-EN 206 [3] used by process engineers and designers lacks information on shrinkage and related test methods, which in practice results in the lack of standardisation.

The main test methods for concrete shrinkage can be divided into laboratory, calculation and specialist methods used on construction sites (Fig. 1).

In the case of laboratory methods, the article describes the concrete shrinkage test using Amsler method according to PN-84/B-06714/23 [4] and a new approach to the method according to PN--EN 12390-16 [5] where both methods show unrestrained shrinkage. The Ring Test method [6, 7] allows for checking the shrinkage of concrete in the event of restrained deformation and thus simulates internal and external constraints occurring in civil engineering structures.

In engineering designs or technical specifications, the value of concrete shrinkage is calculated according to PN-EN 1992-1-1:2008 [8] (calculation method) which allows for forecasting the value of shrinkage deformations of the designed structures.

The specialist methods on site used to determine concrete shrinkage include the use of mechanical, electronic, laser or video sensors. Good examples are vibrating wire transducers and optical fibre sensors which are increasingly used on construction sites.

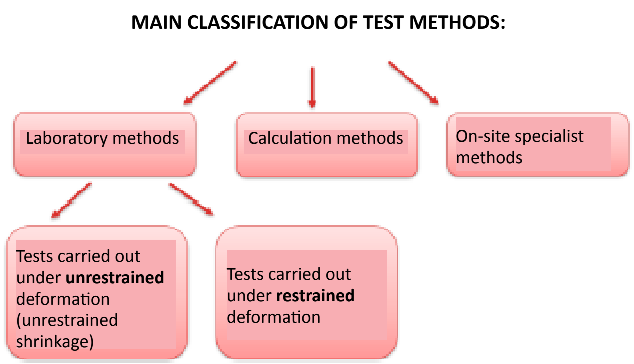

Figure 1 Main classification of concrete shrinkage test methods

The laboratory methods referred to above are included in the comprehensive offer of tests of the TPA Testing Laboratory in Pruszków.
The following section of the article presents the characteristics of selected laboratory test methods which are the most widely used in construction engineering practice.

2.1 Concrete shrinkage test using Amsler method [4]

The test consists in determining the variation in the length of the sample marked with the Amsler testing machine relative to its initial length. The test is performed on 3 concrete samples 10 x 10 x 50 cm (Fig. 2) made using aggregates with a grain size of not more than 16 mm, in accordance with PN-84/B-06714/23 [4]. The first measurement should be performed immediately after deformation of the sample and then the measurements are performed after 3, 7, 14, 28, 60, 90, 120, 150, 210, 270 and 360 days.
Test equipment:
- Amsler testing machine with a micrometer with measurement accuracy up to 0.01 mm;
- measurement standard.

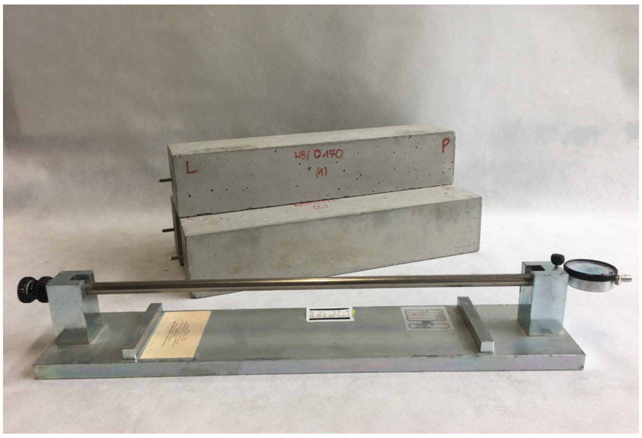

Figure 2 Amsler testing machine with test samples

Test procedure acc. to [4] includes:
- filling the mould with a concrete mix and compaction on the vibrating table;
- placing the moulds with beams in the humidity chamber ensuring a temperature of 18 ± 2°C and humidity above 90%;
- permanent marking of the tested samples, so that each time the gauging point is applied on the same side of the micrometer of the Amsler testing machine;
- during sample measurements, storing of the sample under constant conditions: temperature 18 ± 2°C, relative air humidity 65÷75%;
- immediately before the measurement, checking whether the gauging points on the tested sample are clean, and then making a reading on the measurement standard block (Fig. 3)’
- placing the sample in the Amsler testing machine, pressing the testing machine’s bolt to the steel balls constituting the gauging points, and reading the measurement result on the micrometer pitch with the accuracy of 0.01 mm (Fig. 4) within the established test date.
The change of the length of the samples after n days is calculated according to the formula (1):

$$\varepsilon_n = \frac{(l_n - l_1)\cdot 1000}{500}, \qquad (1)$$

where:
ε_n – change in the sample length [mm/m];
l_n – result of the sample measurement after the lapse of n time in [mm], adjusted by the difference of the reading on the standard in time n in relation to the reading on the standard during the first measurement;
l_1 – result of the first measurement after sample deformation [mm].

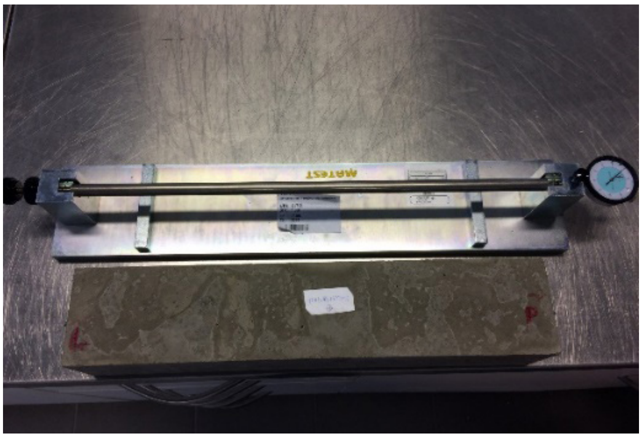

Figure 3 Positioning of the testing machine for testing

Figure 4 Determination of change in the sample length

2.2 Concrete shrinkage test using the Ring Test method [6, 7]

The test consists in determination of the maximum tensile stresses for the tested sample and estimation of the potential for cracking. This test method allows a relative comparison between the materials used and their proportions due to the shrinkage of concrete to be performed. The test is carried out on ring samples with a thickness of 38 mm, made using aggregates with a grain size not exceeding 13 mm. Test procedure acc. to [6, 7] includes:
- filling the mould with a concrete mix and connecting it to the data recorder (Fig. 5), additionally installing a temperature sensor (type K) to monitor the temperature in the concrete mix;

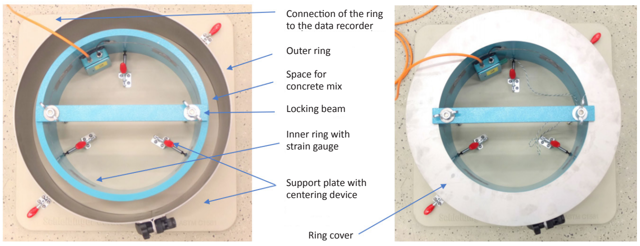

Figure 5 Ring Test equipment [7]

- during the measurements, storing of the samples under constant conditions: temperature 23 ± 2°C, humidity 50 ± 4% (Fig. 6);
- recording deformation and temperature values on a continuous basis from the moment of connection of the rings to the recorder in 30-second intervals.

The Schleibinger system [7] allows the tested samples to be constantly monitored using both numerical data and graphs. The test lasts 28 days, unless the sample breaks – then the test is stopped and documented accordingly.

Figure 6 Samples stored in the climate chamber during the test

The standard [6] provides a classification according to which the potential for cracking (Table 1) can be estimated as high, moderately high, moderately low and low. It depends on the mean value of the stress ratio (S) and the time during which the sample breaks (t_{cr}) or upon completion of the test (t_r).

Table 1 Classification of potential for cracking [6]

Net time to break t_{cr} [days]	Average stress ratio S [psi/day]	Average stress ratio S [MPa/day]	Potential for cracking
$0 < t_{cr} \le 7$	S ≥ 50	S ≥ 0.34	High
$7 < t_{cr} \le 14$	25 ≤ S < 50	0.17 ≤ S < 0.34	Moderately high
$14 < t_{cr} \le 28$	15 ≤ S < 25	0.10 ≤ S < 0.17	Moderately low
$t_{cr} > 28$	S < 15	S < 0.10	Low

The rate of stress rise q for a given sample is calculated according to the formula (2):

$$q = \frac{G \cdot |\alpha_{avq}|}{2 \cdot \sqrt{t_r}}, \quad (2)$$

where:
q – stress increase rate in the sample [MPa/day];
G – 72.2 [GPa];
$|\alpha_n|$ – absolute value from the average coefficient of deformation in the sample [(m/m)/day$^{1/2}$];
t_r – time during which a given sample breaks or time at the end of the test for the sample [days];
S – average stress ratio for three samples: $(q+q_2+q_3)/3$ [MPa/day].

2.3 Concrete shrinkage determination acc. to PN-EN 12390-16 [5]

A new European standard PN-EN 12390-16 [5] has been published this year. The entire test procedure described in this standard allows the total shrinkage value to be calculated, and a separate test methodology for autogenous shrinkage and drying shrinkage is provided (Annex A). At least two samples of a cylindrical or rectangular shape, limited by the ratio of sample length L to dimension d, defined as the diameter or side length of the sample in the range of 2 ≤ L/d ≤ 7, made using aggregates with a grain size not exceeding 32 mm, are to be tested. During measurements the samples should be stored in the climate chamber under the following conditions: temperature 20 ± 2°C, humidity 50÷70 ± 5%. The measuring points may be located in different areas of the tested sample: determined along the main axis of the sample, along a straight line lying on the side surface of the sample or parallel to the main axis, and measuring points in two planes (Fig. 7).

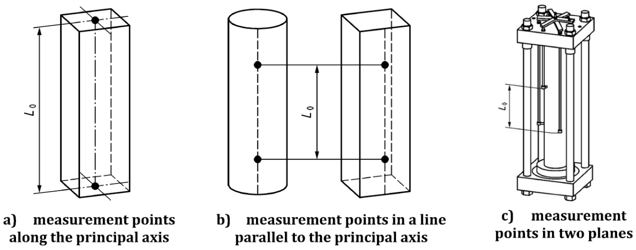

Figure 7 Individual measuring points [5]

Individual days of reading a change in the length of the samples should depend on the determined scope of the test and on the type of concrete tested (the accurate time when the test should be stopped is not provided). In general shrinkage is monitored after 1, 7, 14, 28 and 56 days of concrete maturing. Total shrinkage of the sample, expressed as 10^{-6}, is calculated according to the following formula (3):

$$\varepsilon_{cs}(t, t_0) = (l(t_0)-l_{cs}(t))/L_0, \quad (3)$$

where:
L_0 – distance between measuring points [mm];
$l(t_0)$ – result of the first measurement after sample deformation [mm];
$l_{cs}(t)$ – result of sample measurement after time t [mm];
$\varepsilon_{cs}(t, t_0)$ – total shrinkage after time t.

2.4 Concrete shrinkage according to Eurocode 2 [8, 1]

In engineering designs or technical specifications, the value of concrete shrinkage is calculated according to PN-EN 1992-1-1:2008 [8]. This allows the forecasting of the size of shrinkage deformations of the designed structures, and in the case of determination of actual deformations of the designed concrete on the Amsler beams, it gives an opportunity for comparison of the measured and calculated values [1].
In the calculations according to Eurocode 2 [8], the shrinkage value is affected by, but not limited, the compressive strength of the concrete, the type of cement (S, N or R) and the relative humidity of the environment. The analytical method does not take into account the type and maximum grain size of the aggregate used, the admixture, the w/c ratio and the amount of cement. Total concrete shrinkage (ε_{cs}) consists of two components: shrink deformation due to drying and autogenous shrink deformation. This was described using the formula (4) [8]:

$$\varepsilon_{cs} = \varepsilon_{cd} + \varepsilon_{ca}, \quad (4)$$

where:
ε_{cs} – total shrinkage deformation;
ε_{cd} – drying shrinkage deformation;
ε_{ca} – autogenous shrinkage deformation. Time-dependent drying shrinkage deformation is calculated according to the formula 5 [8]:

$$\varepsilon_{cd}(t) = \beta_{ds}(t, t_s) \cdot k_h \cdot \varepsilon_{cd,0}, \quad (5)$$

$$\beta_{ds}(t, t_s) = \frac{t - t_s}{t - t_s + 0{,}04 \cdot \sqrt{h_0^3}}, \quad (6)$$

$$h_0 = \frac{2 \cdot A_c}{u} = \frac{2 \cdot V_c}{A_{out}}, \quad (7)$$

$$\varepsilon_{cd,0} = 0{,}85 \cdot (220 + 110 \cdot \alpha_{ds1}) \cdot \exp\left(-\alpha_{ds2} \cdot \frac{f_{cm}}{f_{cmo}}\right) \cdot \beta_{RH} \cdot 10^{-6}, \quad (8)$$

$$\beta_{RH} = 1{,}55 \cdot \left[1 - \left(\frac{RH}{RH_0}\right)^3\right], \quad (9)$$

where:
t – concrete age [in days];
t_s – concrete curing period [in days];
h_0 – reliable cross-sectional dimension [mm];
A_c – cross-sectional area of concrete [mm^2];
V_c – volume of concrete block [mm^3];
A_{out} – outer surface of concrete exposed to drying [mm^2];
u – circumference of the part of the cross-section exposed to drying [mm];
k_h – coefficient dependent on reliable dimension h_0 according to standard [8];
α_{ds1} – coefficient dependent on the type of cement;
α_{ds2} – coefficient dependent on the type of cement;
f_{cm} – average concrete compressive strength [MPa];
f_{cm0} = 10 [MPa];
RH – ambient relative humidity [%];
RH_0 = 100 [%].
Autogenous shrinkage deformation is defined according to the formula 10 [8]:

$$\varepsilon_{ca}(t) = \beta_{as}(t) \cdot \varepsilon_{ca}(\infty), \quad (10)$$

$$\varepsilon_{ca}(\infty) = 2{,}5 \cdot (f_{ck} - 10) \cdot 10^{-6}, \quad (11)$$

$$\beta_{as}(t) = 1 - exp \cdot (-0{,}2 \cdot t^{0{,}5}), \quad (12)$$

where:
f_{ck} – characteristic compressive strength of concrete [MPa];
t – concrete age [in days].

3. SUMMARY

The formation of concrete durability is an issue which is technically difficult and responsible due to the necessity of the concrete to meet operational requirements during the service life. This approach requires consideration of the impact of different factors on the earliest possible stage of designing and erecting of concrete structures and components. Based on the experience of the TPA Testing Laboratory in Pruszków, the article presents the characteristics of selected, most useful and commonly used laboratory methods of concrete shrinkage testing. These tests are applied in engineering practice as useful tools to form concrete properties in order to ensure durability and safety during the operation of the facility.

BIBLIOGRAPHY

[1] Kłos K., Kluczowe właściwości betonu płyty dennej w technologii „białej wanny", Praca dyplomowa magisterska, Warszawa 2017.

[2] Kłos K., Jackiewicz-Rek W., Konopska-Piechurska M., Łukowski P., Skurcz betonu stosowanego w technologii „białej wanny", Monografie Technologii Betonu, X Konferencja Dni Betonu, Wisła 2018.

[3] PN-EN 206+A1:2016-12 Beton: wymagania, właściwości, produkcja i zgodność.

[4] PN-84/B-06714/23 Oznaczanie zmian objętościowych metodą Amslera.

[5] PN- EN 12390-16:2020-03 Badania betonu. Część 16: Oznaczanie skurczu betonu.

[6] ASTM C1581-04 Standard Test Method for Determining Age at Cracking and Induced Tensile Stress Characteristics of Mortar and Concrete under Restrained Shrinkage.

[7] Schleibinger ASTM C1581 Shrinkage-Ring, 2017.

[8] PN-EN 1992-1-1:2008 Eurokod 2. Projektowanie konstrukcji z betonu. Część 1-1: Reguły ogólne i reguły dla budynków.