Impact of Selected Environment Conditions on the Shrinkage Strains in Respect to Standard Recommendations

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Abstract. The article discusses the issues related to concrete shrinkage. The basic information on the phenomenon is presented as well as the factors that determine the shrinkage are described. Under laboratory conditions, these factors can be imposed and controlled, but in the field, it is not possible to maintain stable environmental conditions. The paper describes the experimental research that allows determining the effect of changes of humidity and ambient temperature on the values of shrinkage strains in concrete samples and verify the obtained results based on the theoretical model included in the Eurocode 2 standard. The shrinkage strains were measured on samples with dimensions 150x150x600 mm, made of C30/37 concrete with Portland cement and limestone aggregate and with water/cement ratio of 0.43. The samples were divided into two groups - the first group of samples was stored in a chamber with set and controlled values of temperature and humidity, and the second group was left in the laboratory hall with freely changing environmental conditions. The shrinkage strains were measured on samples in accordance with the ITB 194/98 for 175 days. A 20 cm base extensometer was used for the strain measurements. The studies of experimental results of the concrete shrinkage strain are presented with a comparative analysis of the results estimated by the guidelines of the standard according to PN-EN 1992-1-1:2008. The obtained results confirmed that the unstable humidity as well as temperature have a significant impact on the course of shrinkage strains in concrete and they both should be taken into consideration during performing concrete elements.

1. Introduction
Concrete shrinkage is a rheological phenomenon caused by physical-chemical processes that occur during mix setting (autogenous shrinkage) and concrete hardening (drying shrinkage). The results of these structural changes are self-generated shrinkage strains. Autogenous shrinkage is caused by loss of water due to cement hydration. This kind of shrinkage appears in the first hours of setting and grows rapidly in the few next days but it has no significant impact on the overall shrinkage strain in the concrete element. On the other hand, the hardened concrete loses water due to drying that leads to the drying shrinkage. The drying shrinkage is growing much slower than autogenous shrinkage but for many years and it is a significant part of the overall shrinkage strain [1-3].

The shrinkage course and size depend on many factors, i.e.: the type and the class of cement, as well as the mix quantity, w/c ratio, type and granulation of aggregates, class and age of concrete, dimensions of the element, mechanical limits of strain in concrete (e.g. as a result of reinforcement) [1-3] and the concrete admixtures [4-5]. The specific use conditions of reinforced concrete elements affect the shrinkage strains also, what was described in [6] based on the research of concrete airfield pavements exposed on the high temperature effects. However, the biggest influence on the shrinkage...
development have the environmental conditions, particularly humidity that affect the rate of water evaporation.

It is important to know that the concrete shrinkage appears in the moment of the physical-chemical water loss, i.e. the water that comes from the cement grout [5]. Evaporation of the water that fills the big pores in the concrete does not affect the shrinkage. Therefore, the appropriate curing of concrete from the start of mix setting is very important. If the environmental humidity value is not less than HR=90% the shrinkage strain can be significantly limited, intermitted or even the phenomenon of concrete swelling is observed (as in the case of specimens kept in water). The swelling may reach about 0.1÷0.2 mm/m. The maintain of high humidity in the first 7-14 days of concrete setting and hardening reduces the negative shrinkage effect – shrinkage cracks are limited [7, 8]. The convenient environmental conditions are easy to achieve in the laboratory for small specimens. However, the impact of environmental conditions on the shrinkage of real elements of building structures may be controlled only in limited scope.

The values of shrinkage strain can be estimated on the basis of the Eurocode standards, i.e. [9] and [10]. These standards allow calculating the total shrinkage strain as well as the autogenous shrinkage or the drying shrinkage [7, 8]. The procedures take into consideration both, the influence of inner factors (e.g. concrete mix, age of element, dimensions, etc.) and the environmental condition (humidity) on the overall concrete shrinkage.

According to the given guidelines [9, 10] the total shrinkage strain $\varepsilon_{cs}$ is the sum of two components:

$$\varepsilon_{cs} = \varepsilon_{ca} + \varepsilon_{cd}$$  \hspace{1cm} (1)

where: $\varepsilon_{ca}$ – autogenous shrinkage strain, $\varepsilon_{cd}$ – drying shrinkage strain.

Autogenous shrinkage strain developing in time $\varepsilon_{ca}(t)$ is defined by the function:

$$\varepsilon_{ca}(t) = \beta_{as}(t) \cdot \varepsilon_{ca}(\infty)$$  \hspace{1cm} (2)

where:
- $\beta_{as}(t)$ – shrinkage coefficient determining the change in function of time, $\beta_{as}(t) = 1 - \exp(-0.2 \cdot t^{0.5})$
- $t$ – concrete age (days),
- $\varepsilon_{ca}(\infty)$ – final autogenous shrinkage strain, $\varepsilon_{ca}(\infty) = 2.5 \cdot (f_{ck} - 10) \cdot 10^{-6}$

The shrinkage strain caused by drying is given by the formula:

$$\varepsilon_{cd,0} = k_h \cdot \varepsilon_{cd,0}$$  \hspace{1cm} (3)

where:
- $k_h$ – coefficient depending on the notional size $h_0$, $h_0 = \frac{2A_c}{u}$
- $A_c$ – concrete cross-sectional area,
- $u$ – perimeter of that part of the cross section which is exposed to drying,
- $\varepsilon_{cd,0}$ – nominal drying shrinkage strain,

$$\varepsilon_{cd,0} = 0.85 \cdot (220 + 100 \cdot \alpha_{dil}) \cdot \exp\left(-\alpha_{dil} \cdot \frac{f_{cm}}{f_{cm,0}}\right) \cdot \beta_{RH} \cdot 10^{-6}$$  \hspace{1cm} (4)

where:
- $f_{cm}$ – mean compressive concrete strength [MPa],
- $f_{cm,0} = 10 \text{ MPA}$.
- $\alpha_{d1}, \alpha_{d2}$ - coefficients depending on the cement kind,

- $R_H$ - the ambient relative humidity [%], $\beta_{RH} = 1.55 \left(1 - \frac{R_H}{R_{H_0}}\right)^3$,

- $R_{H_0} = 100\%$, $\beta_{RH}$ - coefficient depending on the ambient relative humidity.

Based on the above formulas, it is visible that the differences in shrinkage values in the elements made of the same concrete mix, in the same age and dimensions will be follow only from the different environmental humidity. The influence of other environmental parameters (e.g. temperature or air circulation) is not considered. However, the temperature or the force of the wind for example determine the intensity of physical-chemical concrete reactions, particularly in the case of erection and use of the real concrete buildings. In addition, the possibility of controlling the environmental conditions in this case is limited or even impossible (differently than in laboratory test).

The paper presents the results of shrinkage test that was performed on concrete samples (made of concrete class C30/37 with admixtures). The samples were divided into two groups, stored in different environmental conditions - the first group of samples was stored in a chamber with set, and controlled values of temperature and humidity, and the second group was left in the laboratory hall with freely changing environmental conditions. The objective of this work was to determine the impact of environmental conditions on the values of shrinkage strains in samples and the results verification on the basis on the Eurocode 2 standard [9].

2. Experimental research

Twelve reinforced concrete specimens 150×150×150 mm were prepared for the tests. The specimens were made of C30/37 concrete, consistency class S3, water/cement ratio w/c = 0.43. Concrete mix components per 1 m³ are shown in the table 1.

| Limestone 2-8 | Limestone 8-16 | Sand 0-2 | CEM I 42.5 N MSR/NA | Water | Air entraining admixture | Plasticizer |
|---------------|----------------|---------|---------------------|-------|--------------------------|------------|
| 600           | 650            | 680     | 384                 | 166   | 0.77                     | 1.90       |

Shrinkage measurements were carried out according to [11] for 205 days. On each side of each sample (immediately after removing them from moulds), two metal benchmarks were stuck (figure 1) and the basic longitudinal strains were measured.

Figure 1. The spacing of metal marks to strain measurements on the sample

Six samples were marked with the symbol K (K1-K6) and placed in a thermal chamber (figure 2a) with a capacity of 0.67 m³. The temperature in the chamber was set at 24 ± 2 °C. The temperature and humidity inside the chamber were recorded continuously. The other 6 samples were marked with the symbol H (H1-H6) and left in the laboratory hall of considerable dimensions: 35.9x12.7x9.6 m (about
4300 m³), in which the elements matured in not imposed temperature and humidity conditions (figure 2b). At that time, the hall was used in a typical manner, independent tests were carried out, i.e. concreting, destructive tests of various elements, the hall was ventilated, seasonally heated, etc. The temperature and humidity were measured using two independent electronic thermo-hygrometers located within 1m from tested samples.

![Figure 2. Test samples: a) in the thermal chamber, b) in the laboratory hall](image)

The strain measurements were made mechanically using a Demec extensometer (figure 3) with a measuring base of 200 mm and an accuracy of 0.002 mm (extensometer’s constant 0.79 x 10⁻⁵). Studies were performed at specified intervals, taking into account the guidelines specified in the Instruction [11]. The obtained experimental results were compared with the values of strains calculated according to the standard [9].

![Figure 3. Strain measurements by using the extensometer](image)

3. Analysis of the research

On the basis of the measurements made on each of the four walls of all tested samples, mean values of shrinkage strains were determined for both types of H and K samples.

Figure 4 shows the graphs of the average shrinkage strains measured in samples K (placed in the thermal chamber) and estimated according to the standard [9] and their trend lines. The figure 4 also shows the values of recorded temperature and humidity. It can be noticed that the experimental and calculated values of shrinkage strains did not differ significantly, and the trend lines (logarithmic) almost overlapped. The biggest differences were visible on the 30th and 42nd day of measurements - the computational shrinkage values were ~ 10% greater than the experimental ones. The large increase in computational shrinkage resulted from changes in humidity. In these days, the humidity dropped from 66.5% to 62.9% (30 days) and from 67% to 62.8% (42 days), respectively.
It should be noted that the experimental values did not increase in proportion to the calculation. It can therefore be assumed that shrinkage in hardened concrete is not as sensitive to changes in humidity as is evidenced by the norm or that the sudden change in humidity does not cause sudden changes in shrinkage and slightly delayed, because in the following days the values of experimental and computational shrinkage were again similar.

**Figure 4.** Graph of average shrinkage strains determined for K samples and estimated according to the standard [9] with their trend lines and temperature and humidity conditions

A similar analysis, as for K samples, was carried out for H samples (placed in the laboratory hall). Figure 5 shows the graphs of average shrinkage strains measured in H samples and estimated according to the standard [9] with their trend lines and temperature and humidity courses. In this case, it can be seen that the course of experimental and computational shrinkage did not overlap (trend lines were divergent) except the first 18 days of measurements - during this time both curves almost overlap. After this period, the experimental shrinkage values were lower than the computational one (by 12% to 35%). This trend was maintained up to ~ 150 days of measurements. At the end of the test, the experimental and computational shrinkage values were similar again (the maximum difference of the last day of the measurements was ~ 7%). Observing both curves we can see the effect of changes in humidity on shrinkage values, although (as in K samples) it seems that the experimental samples react with a certain delay. It can also be seen that changes in the experimental shrinkage result not only from changes in humidity, but also from temperature (or from other ambient factors that have not been measured).
Figure 5. Graph of average shrinkage strains determined for H samples and estimated according to the standard [9] with their trend lines and temperature and humidity conditions.

Figure 6 presents the average values of shrinkage measured in samples H and K with the recorded ambient humidity. The analysis of the results confirmed that the ambient conditions have a significant impact on the values of the shrinkage strain. Although all samples were made of the same concrete mix, there are clear differences in the shrinkage values of K samples (stored in the chamber) and H samples (left in the laboratory) - K samples were characterized by a higher shrinkage than the H samples. Only in the first days of measurements, these values were similar (to ~ 18 days). In the following days, differences in the values of shrinkage strains ranged from 21% (on day 34 of the study) to as much as 33% (on 103 days of the study). Interestingly, in the first days of the study, when the shrinkage in both types of samples was almost identical, the ambient humidity was clearly different. Probably the effect on similar shrinkage values in samples K and H on these days had the same humidity of the samples just after demoulding. Throughout the study, shrinkage in K samples steadily increased, which was associated with a systematic decrease in humidity in the chamber. Shrinkage in H samples did not increase as regularly as the ambient humidity changed irregularly. However, it should be added that the course of shrinkage in H samples is not synonymous with changes in humidity. Probably the size of the shrinkage was also affected by other environmental factors, e.g. temperature or air blast.

It can be assumed that the shrinkage of concrete in real structural elements (which are used under environmental conditions with unknown values of humidity, temperature and other environmental parameters) may significantly differ from the standard strain. The shrinkage calculated according to the standard is only an estimated value with a greater or lesser probability.
4. Conclusions

On the basis of the examinations and analyses carried out, the following conclusions were formulated:

- Experimental research confirms that environmental conditions, mainly humidity, have a significant impact on the course and size of shrinkage strains.
- For samples placed in a thermal chamber with small dimensions and with an impossibly air circulation, experimental values of shrinkage correspond well with the values determined by the standard [9].
- In the case of samples stored in the laboratory hall, there are large incompatibilities in the values of the shrinkage strains obtained from experimental tests and estimated according to the standard [9].
- Apart from ambient humidity, temperature and air circulation (which are not included in the standard guidelines) may affect the shrinkage in the concrete [9].
- It should be remembered that the shrinkage strains calculated on the basis of the standard [9] have only an estimated value and in some cases may deviate significantly from the actual values.

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