Experimental measurement of volume changes of cement concrete specimens

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Abstract: The paper describes experimental measurement of volume changes of cement concrete. Shrinkage is now becoming increasingly important with respect to concrete construction requirements, and it is important to be able to accurately measure and evaluate volume changes.Volume changes include swelling and shrinkage of cement concrete specimens. The experiment includes evaluating effects on volume changes and, depending on the environment, also evaluating individual types of volume changes in concrete such as drying shrinkage and thermal expansion. Volume changes was measured by string strain gauges both internal and external (with experimental casting method). The specimens were located in the laboratory and in the outdoor environment, so it was possible to compare values from different environments. Within the experiment, the measurement methodology of string strain gauges was unified for future experiments, which was one of the experiment goals. The measured results are compared with the calculation model of shrinkage (model B4). Comparison of shrinkage results with calculation models is important in designing concrete structures and developing other parameters for calculation models. The results from the experiment will serve to further investigate the volume changes depending on the subsoil. The concrete used in the experiment served as comparative, and the measured values would serve as a benchmark for dispersed reinforcement (steel fibers) concrete proposed in future experiments. Concretes with dispersed reinforcement using steel fibers has a positive effect on the reduction of volume changes and measurement of these concretes will be the next step of the research with the emphasis on building practice, especially industrial floors.

Key-Words: Concrete, Volume Changes, Shrinkage, Swelling, Model B4, Cement

1 Introduction

The volume changes of cement concrete are a phenomenon that accompanies setting and hardening of concrete from the very beginning. From the point of view of the composition of conventional cement concrete, swelling occurs in the first hours and days, which in a certain period of time will prevail in a gradual shrinkage. This behavior can generally be described as volume changes. These volume changes are, in terms of composition, associated with hydration of the cement binder when chemical reactions occur. Depending on the composition of the concrete, the amount of cement and the size of the water-cement ratio, the volume changes are different. Although the volume changes due to hydration are well described theoretically, the whole process is not thoroughly investigated. In addition to volume changes caused by hydration, the volume changes also affect the surrounding environment, and it is necessary to be able to separate these effects on volume changes. Volumetric changes due to the composition of concrete can be prevented by proper care. The negative impact of shrinkage of concrete, in the extreme case leading to cracks, can be reduced. [1; 2; 3; 4; 6]

The experiment aims to separate the individual effects causing volume changes. A large-scale specimen placed in the laboratory will be subject to drying shrinkage due to the composition. A specimen located outside the laboratory, outdoors, will be subject to external climatic influences. In addition to drying shrinkage, volume changes due to temperature changes will also have to be considered here. Other types of shrinking may be neglected in this experiment. In particular autogenous shrinkage is not necessary due to the high water-cement ratio. [2]

2 Experimental part

The description of the experiment is divided into three logical chapters, detailing the steps from design of concrete through curing to measurement of specimens.

2.1 Composition of concrete

The concrete C30/37-XC4 was designed for the experiment. Since the intention was to eliminate as much of the phenomena as possible in terms of composition, which could have an impact on volume changes, no addition was given to the concrete and no aerated concrete was proposed. The strength class has been chosen in view of the frequent use of this strength class in practice and at the same time with a high dose of cement with the assumption of high shrinkage. Concrete has been designed in accordance with EN 206, where requirements for the composition of this concrete are defined. The technical standard requires a minimum amount of cement (300 kg/m^3), maximum water-cement ration (w/c = 0.5) and strength class (25/30). The designed concrete meets stricter requirements to the standard, because 345 kg/m^3 of Portland cement CEM I 42.5 R was delivered, resulting in a higher strength class. The water-cement ratio was 0,5. The superplasticizing admixture has been dosed into the concrete to provide the desired water-cement ration and S3 consistency. After the concrete was cast into formwork, curing of concrete was started immediately at the beginning of setting and in the same time started measurements of volume changes using string strain gauges. For the determination of compressive strength and modulus of elasticity after 7 and 28 days, samples were taken at a quantity of 6 cylinders for each test. Determination of strength and modulus of elasticity is important for computational models.

2.2 Specimens, casting and curing of concrete

Specimens were designed in size 150 x 500 x 6000 mm. One sample was placed in the laboratory and the second was placed outside the laboratory in an outdoor environment where the specimen was exposed to external climatic conditions including precipitation. Concrete was cast into wooden formwork. The bottom of the formworks was covered with PE foil to ensure zero water removal from the lower surface (avoiding plastic shrinkage) as well as lower friction of the concrete.

Concrete was cast directly from the agitating truck by using a trough and compacted by a submersible vibrator. The specimens were immediately covered with geotextile at the beginning of the setting of the concrete and cured with water for 5 days. Geotextiles were removed after curing, and lateral stripping was performed. The specimen in the laboratory was kept permanently in an environment having a temperature of 20 ± 2 ° C and a relative humidity of 55 ± 5%.

2.3 Measurement with string strain gauges

For measuring volume changes on specimens were used string strain gauges EDS-20-E. Three string strain gauges were placed in each sample at 1,5 m apart, counted from the edge of the specimen along the length. These internal string strain gauges were at a height of 50 ± 10 mm from the lower surface of the specimen. The internal string strain gauges were fixes using steel hooks and a binding wire. Experimentally, one string strain gauge was placed on the surface of the samples to half the length (3 m). String strain gauges on surface were fixed using steel U-profiles, which were vertically placed in a setting concrete to a depth of about 20 mm. String strain gauges were fixed on 10 mm long protruding ends above the surface. This joint was reinforced with covering thick layer of concrete. The value readings were performed using the Gage GT1174-3 control panel at least once every day since the concrete was cast.

3 Evaluation of results

The experiment was evaluated after 3 months. Measurement of volumetric changes using string strain gauges is shown in the graph in Fig. 1. The measured values are already recalculated for correction to the temperature of the string strain gauge, since the influence of hydration also occurs in the laboratory at rapid temperature changes and these changes in the extensibility of the concrete and the string strain gauge it's necessary consider. For non-laboratory specimens, this must be considered for changes in climatic temperatures. In view of the constant ambient conditions in the laboratory, a specimen placed in the laboratory will be commented on first. It can be seen from the graph that the sample due to the higher temperature caused by the hydration of cement and the supply of water from the curing began to swell immediately at the beginning of the setting. Swelling is also caused by the creation of new hydrating minerals such as C_3A and C_2S, but the phenomenon is minimal in concrete and does not form the dominant part of the swelling compared to other influences [5]. Furthermore, swelling is lower on the surface where direct contact with cold water (and with generally lower ambient temperature) occurs. After 5 days when water curing was ended, the specimen began to shrink by drying. Again, a trend is observed when the shrinkage by drying is more dynamic on the surface, and in later stages it is slower and has lower values than volume changes within the sample.

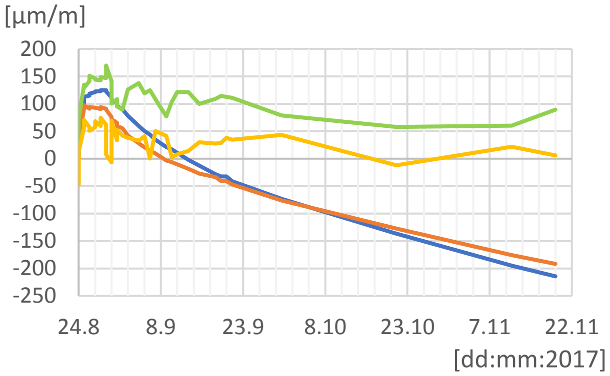

Fig. 1 – Comparison of volume changes of specimens. Blue: Laboratory – internal; Orange: Laboratory – external; Green: Outdoor – internal; Yellow: Outdoor - external

For the sample exposed to climatic conditions, the analysis in the above paragraph applies, but additional significant influences, variable temperature and relative humidity are added. For this specimen, it can be stated that in the total sum of all influences, including the initial swelling, values of volume changes did not exceed the zero. Therefore, the curves are not in the range of the negative values that describe the shrinkage of the specimen, as is evident in the specimen placed in the laboratory. The shrinkage of drying is undoubtedly occurring (as will be explained in Fig. 2), but this phenomenon is denied by other influences such as concrete expansion and water absorption. It is certain that the final shrinkage values will always be lower than in the laboratory specimen, as the water is supplied due to precipitation and absorption of air humidity.

In the graph in Fig. 2 a comparison of the final shrinkage after 3 months is made on large-scale specimens and the graph is further supplemented by the curves according to the calculation model B4. Model B4 is currently the most sophisticated shrinkage calculation model. It considers the most parameters and boundary conditions, and it is possible to incorporate as many variables into the calculation. For these reasons, the B4 has been chosen as a default model for comparison, but the author considers future models to be considered (Eurocode, Model Code, etc.). [7]

To compare specimen's shrinkage values with a calculation model that does not consider swelling due to hydration and during curing, it was necessary to recalculate the volume changes of the measured specimens and limit them only to shrinkage. The specimens began to shrink after ending of curing, which was after 5 days. The highest swelling value was defined zero for the calculation and the shrinkage began to count from this value. Therefore, the shrinkage values are higher than in Fig. 1.

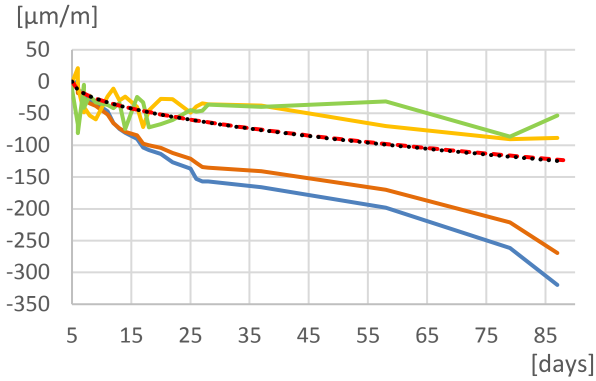

Fig. 2 – Comparison of shrinkage of specimens and model B4. Blue: Laboratory – internal; Orange: Laboratory – external; Green: Outdoor – internal; Yellow: Outdoor – external; Red: Laboratory – B4; Black: Outdoor – B4

It can be seen from Fig. 4 that the calculated shrinkage of the B4 model is almost the same in the laboratory and outdoor environment. Compared to the real results of the laboratory specimen, however, it is considerably underestimated. The shrinkage process is not so dynamic and the final shrinkage values are lower. Compared to a specimen that was stored in a real environment, the values of the final shrinking of the computational model are higher. The curve of the computational model at a later stage is most closely approaching the yellow curve describing the outdoor sample with string strain gauges located inside the concrete. The shrinkage fluctuations in the outdoor sample are due to temperature changes due to precipitation and varying relative humidity.

4 Conclusion

The paper describes the measurement of volume changes of cement concrete on large-dimensional specimens. Since it was an input "zero" experiment, the purpose was primarily to unify methodologies and procedures. The research will continue by measuring other concrete designs or by simulating other effects of volume changes. The author continues to measure the specimens, because after three months the volume changes continue as expected.

The experiment confirmed the known phenomena of volume changes in cement concrete, however the author also considers that in the case of large-scale specimens, the subsoil and the weight of the specimen are also significant in the shrinkage size. The actual weight of the sample affects the bottom surface and thus increases friction depending on the substrate material. Further attention will be paid to this phenomenon and will be one of the other research directions.

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References:

[1] AÏTCIN, Pierre-Claude. *Binders for durable and sustainable concrete*. New York: Taylor & Francis, 2008. ISBN 978–0–203–94048–8.

[2] AÏTCIN, Pierre-Claude a Sidney. MINDESS. *Sustainability of concrete*. New York: Spon Press, 2011. Modern concrete technology, 17. ISBN 978-0-203-85663-5.

[3] BAŽANT, Zdeněk. RILEM draft recommendation: TC-242-MDC multi-decade creep and shrinkage of concrete. *Materials and Structures*. 2015, **48**(4), 753-770. DOI: 10.1617/s11527-014-0485-2. ISSN 1359-5997.

[4] ED. BY A. BENTUR. *Early age cracking in cementitious systems: report of RILEM Technical Committee 181-EAS 'Early Age Shrinkage Induced Stresses and Cracking in Cementitious Systems'*. Bagneux: RILEM Publ, 2003. ISBN 2912143330.

[5] KROPÁČEK, Michal a Jiří ŠAFRATA. Objemové změny cementů z různých lokalit v závislosti na čase. *Sborník vědeckých prací Vysoké školy báňské – Technické univerzity Ostrava. Řada stavební*. 2015, **15**(1), 11-20. ISSN 1213-1962.

[6] HAVLÁSEK, Petr. *Creep and Shrinkage of Concrete Subjected to Variable Environmental Conditions*. Praha, 2014. Doctoral thesis. Czech technical university in Prague. Vedoucí práce Milan Jirásek.

[7] VINKLER, Marek a Jan L. VÍTEK. Drying shrinkage of concrete elements: Structural Concrete. *Structural Concrete*. 2017, **18**(1), 92-103. DOI: 10.1002/suco.201500208. ISSN 14644177.