Experimental measurement of volume changes of cement composites using Portland cements from different locations

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Abstract: The paper describes experimental measurement of volume changes of cement composites. The first part of the experiment describes the measurement of volume changes of cement mortars. The mortars were designed in accordance with standard EN 196-1 [6]. Only the binder used differed in the mortars, which were Portland cements CEM I 42,5R from different production sites (5 cement plants). The second part of the experiment is the measurement of cement concrete under different conditions with using Portland cement CEM I 42.5 R as a binder. The concrete was designed in accordance with EN 206 [8] standard. Volume changes were measured by the shrinkage-drain, which allows to measure volume changes in the early setting and hardening phases. The volume changes of cement composites are a significant cause of negative symptoms, which can lead to cracks. The aim of the experiment was to assess the behavior of individual cements over a longer period in terms of volume changes and compare them among themselves. The experiment evaluates the stability of production of individual cements and, in view of the different input raw materials, compares the course of volume changes of cements from different cement plants. All Portlands cements comply with the requirements of the relevant EN 197-1 [7] standard, which, in the light of the results found, makes the experiment more unique. The experiment shows deviations in the composition and surrounding conditions that affect the final behaviour of mortar or concrete in terms of volume changes, which is beneficial to building practice and in particular to concrete technology. The experiment is also basis for calculation models, which will be the subject of further research.

Key-Words: Mortar, Concrete, Volume Changes, Shrinkage, Swelling, Portland cement, Shrinkage-Drain

1 Introduction

The binder is the main agent of volume changes, namely shrinkage in mortars and concrete. Below the term “binder” should be read cement, the largest of which has a shrinkage of Portland cement (CEM I 42.5 R). Portland cement is composed of a dominant part of the clinker (95 to 100 %), which is composed of minerals. These minerals (C_3S; C_2S; C_3A; C_4AF and others) undergo different shrinkage during hydration, which occurs at each mineral of varying intensity. The lowest tendency to shrinkage has minerals C_4AF and C_2S, mineral with the highest clinker content C_3S has a mean shrinkage, and C_3A causes significant shrinkage, besides being volatile in the long run, which also indicates a certain tendency to lower C_3A. The remaining 5 % of Portland cement composition is Gypsum for regulating of reaction of cement and other additives adjust the quality of cement. Besides the chemical composition of the cement, the specific surface has a significant influence on shrinkage. The finer the cement is, the more reactive it is. It can be said that a finer grinding ensures a better and faster hydration of all cement grains, which also results in greater shrinkage and increased water consumption. [1; 3; 5; 9; 11]

In conventional mortar or concrete, where binder is Portland cement, swelling occurs in the first hours and days. This swelling is caused by the formation of minerals such as ettringite and portlandite. On increasing the volume has a proportion of C-S-H gel, which absorbs water between its layers. After this swelling, the cement binder passes in a gradual shrinkage. This process can be summarized as volume changes. In addition to the binder itself, the volume changes affect other parameters, which includes amount of binder, size of the water-binder ratio, and size of the binder-aggregate ratio. The final composition of the composite is thus a key factor in subsequent behavior in the construction. Besides the composition itself, ambient conditions, in particular temperature and relative air humidity, have a significant impact on volume changes. Each mortar and concrete require proper curing, allowing it to effectively reduce volume changes and a negative shrinkage effect leading to cracks. [1; 2; 3; 5; 9; 10; 16]

This unique experiment aims to measure volume changes on various Portland cements (CEM I 42.5 R) that are produced in the Czech Republic from different cement plants for defined period. Measurements were made on mortars made in accordance with the technical standard EN 196-1 [6] in order to ensure uniform conditions and the only variable was the chosen Portland cement. Measurement of cement mortars took place exclusively in the laboratory and, given the high water-cement ratio, it was possible to neglect autogenous shrinkage [1; 2; 17]. Under the conditions thus defined, it was possible to ensure that the specimens would pass through the initial swelling and subsequently shrink due to chemical shrinkage and shrinkage by drying. The volume changes were made using shrinkage-drains by company Schleibinger, which allow continuous measurement of volume changes from the beginning of setting of mortar or concrete (depends only on the dimension of the drain).

Furthermore, similar measurements were made on cement concrete, where Portland cement (CEM I 42.5 R) was used as a binder by one cement plant. The volume changes of concrete here have the same defined conditions as the experiment with cement mortar and the specimens were measured in different environments. Measurement in different environments on the same specimen is a significant part of the experiment. Generally mortars and concrete are behave differently in the laboratory and in the outdoor environment in terms of volume changes, which is caused by environmental conditions as mentioned in the paragraphs above. Relevant data on concrete behavior in terms of volume changes compared to the laboratory and casting in real conditions are an important basis for calculation models. The calculations models are constantly under development and are capable of accurately determining the final shrinkage of the concrete, but they do not even consider the influence of the subsoil and sliding joints. These two parameters have a significant influence on the development of volume changes and final shrinkage in terms of friction. [4; 12; 13; 14; 15; 18]

2 Experimental part

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

2.1 Composition of mortar

For testing was used Portland cements (CEM I 42,5 R), which was taken from all cement plants in Czech Republic for a defined period. Producers of cement are listed in the following list:

LaFarge Cement Cizkovice
Buzzi Unicem Cement Hranice
HeidelbergCement Ceskomoravsky cement Mokra
Cemex Prachovice
HeidelbergCement Ceskomoravsky cement Radotin

Those cements were dosed into the mortar in accordance with norm EN 196-1 [6]. Standard mortar has a defined composition in ratio 2 (cement) to 6 (standard silica sand) to 1 (water). The resulting water-cement ratio is 0.5. After the mortar was cast into shrinkage-drain, curing of concrete was started immediately at the beginning of setting and in the same time started measurements of volume changes.

2.2 Composition of cement

For the experiment was designed concrete C30/37-XC4. 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. Concrete has been designed in accordance with EN 206 [8], where requirements for the composition of this concrete are defined. In concrete was 345 kg/m^3 of Portland cement CEM I 42.5 R from cement plant Hranice. The water-cement ratio was 0.5. The superplasticizing admixture has been dosed into the concrete to provide S3 consistency. After the concrete was cast into shrinkage-drain, curing of concrete was started immediately at the beginning of setting and in the same time started measurements of volume changes.

2.3 Measurement of mortar with shrinkage-drain

Volume changes were measured by shrinkage-drains from company Schleibinger designed for cement mortars. Drains have a dimension 40 (height) x 60 (width) and 1000 (length) mm. The inner u-profile of the shrinkage-drain was covered with PE foil to ensure lower friction of the mortar. Volume changes were measured on the cements each one month of production. These takings lasted for 5 to 7 months for each cement. The shrinkage-drains were placed for 7 days in the air-conditioned chamber, where the temperature was maintained at

20 ± 2 ° C and relative humidity was higher than 95 %, which are the ideal conditions for the curing of cement mortar (Fig. 2). During this time (7 days) continuous measurement of the specimens in shrinkage-drains was carried out with automatic readings every 15 minutes from the setting of the mortar.

After 7 days was hardened testing specimens removed from air-conditioned chamber and with pre-glued steel spots (Fig. 1) continued measurement by deformeter. It went until 2 consecutive measurement have the same results.

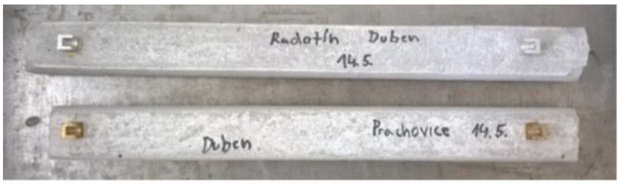

Fig. 1 – Shrinkage-drains in air-conditioned chamber

2.4 Measurement of concrete with shrinkage-drain

Volume changes was measured by shrinkage-drains designed for concrete and the test procedure was similar to the procedure described in Section 2.3 Drains have a dimension 60 (height) x 100 (width) and 1000 (length) mm. Volume changes were measured in three shrinkage-drains. The two drains were placed for 5 days in the air-conditioned chamber, where the temperature was maintained at 20 ± 2 ° C and relative humidity was higher than 95 %, which is the ideal conditions for the curing of concrete (Fig. 2).

Fig. 2 – Shrinkage-drains in air-conditioned chamber

One shrinkage-drain was wrapped in a foil and left in a laboratory room where the same standard temperature was maintained. Relative humidity varied and ranged on average about 55 %. This simulated the condition, where the concrete does not have any supply of water, but the specimen is prevented from losing water due to drying.

The measurement procedure was the same as for mortar specimens, but after 5 days, the two remaining specimens were placed in different environments. The first specimen was placed in the laboratory space from the air-conditioned chamber and the other was placed in an outdoor environment where it was exposed to changing climatic conditions. It is necessary to add that a specimen placed outside the laboratory was under the roof and could not receive water due to precipitation.

3 Evaluation of results

This paragraph contains an evaluation of the results measured by shrinkage-drains for mortars and concrete. Although there is a lot of information about chemistry and the principle of volume changes common, it is advantageous to separate these chapters from one another.

3.1 Results for cement mortars

From the point of view of the evaluation of the measured results, it can be generally stated that for each cement in early setting and hardening swelling occurs, which is in line with the description of chemical reactions in the theoretical part. Here it is necessary to add that the swelling occurred in an environment with relative humidity of over 90 % and it can be assumed that if the specimens were stored in the water, the swelling would be even higher. Acquisition occurs due to the creation of hydrating products that show rapid growth. The dominant part of the phenomenon is responsible for Ettringite, but Portlandite is similar in its behavior. Growth of Ettringite occurs within a few hours, which also means that after a certain amount of time the shrinkage is shifted. However, in the ideal environment, this shrinkage does not decrease to negative values (reduces swelling), resulting in no shrinkage cracks, confirming the need for precision curing in the early stages. After 7 days the specimens were removed from the ideal environment (air-conditioned chamber) and left in a laboratory environment. Chemical shrinkage is thus added to the drying shrinkage. Chemical shrinkage occurs until cement hydration is complete, which is normally a long-term process that depends, among other things, on the fineness of milling of the cement. Drying shrinkage always occurs when switching from the ideal environment to normal, but the goal is to delay this transition until the composite has the needed tensile strength to minimize the shrinkage.

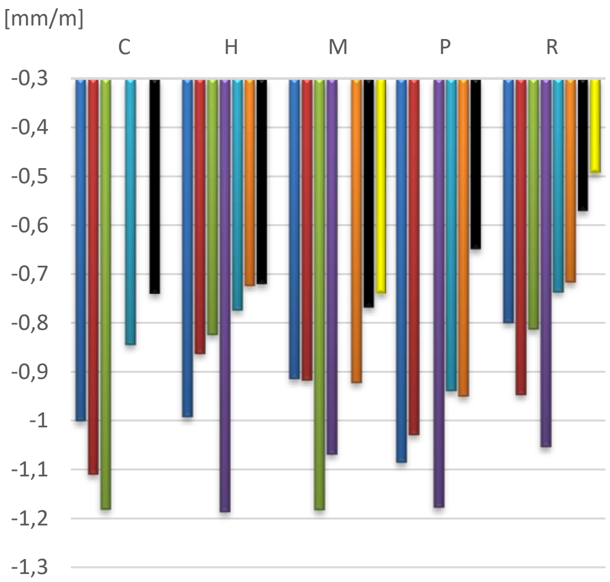

Fig. 3 – Comparison of volume changes of cement mortar specimens. Legend: C = Cizkovice; H = Hranice; M = Mokra; P = Prachovice; R = Radotin; Blue – November; Red – December; Green – January; Purple – February; Turquoise – March; Orange – April; Black – May; Yellow – June

From the point of view of the actual evaluation of the practical results, it is very difficult to decide which Portland cement is the most stable or has the lowest shrinkage (Fig. 3). The lowest shrinkage value, despite the high variability, shows Portland cement from cement plant Radotin, where only one specimen exceeded the shrinkage value of 1 mm / m. Similar values are also found in the cement Hranice, where only one value deviates significantly from the others. Stability over time is very variable for all Portland cements, if a significantly deviating result in one specimen would be eliminated at the cement Hranice, it would be the most stable cement. A low shrinkage rate over time also has cement from cement plant Prachovice, but it has a significantly higher shrinkage.

3.2 Results for cement concrete

The course of volume changes was very similar to that of cement mortar. The same theoretical explanation applies to all hydration processes as in Chapter 3.1. On the Fig. 4 can be seen, that for all three specimens first shrinking and then swelling in the range of 12 to 24 hours. After 5 days, the specimens began to shrink due to drying shrinkage. The largest drying shrinkage has a specimen that was placed in the laboratory after being cured in the air-conditioned chamber. The lowest shrinkage shows a specimen that was placed in the outdoor environment after curing in the air-conditioned chamber. It is known that the changing relative humidity and the absorption of air humidity in the porous structure of the concrete can cause a significant decrease of drying shrinkage. For the specimen placed in the laboratory, only the upper surface was exposed at the end of the curing period. Final value of drying shrinkage is slower, and the final value is lower than the specimen exposed to the shrinkage by drying from the sides. The values shown on Fig. 4 are final, because values of shrinkage are constant, and the residual moisture of the specimens is around 1 %.

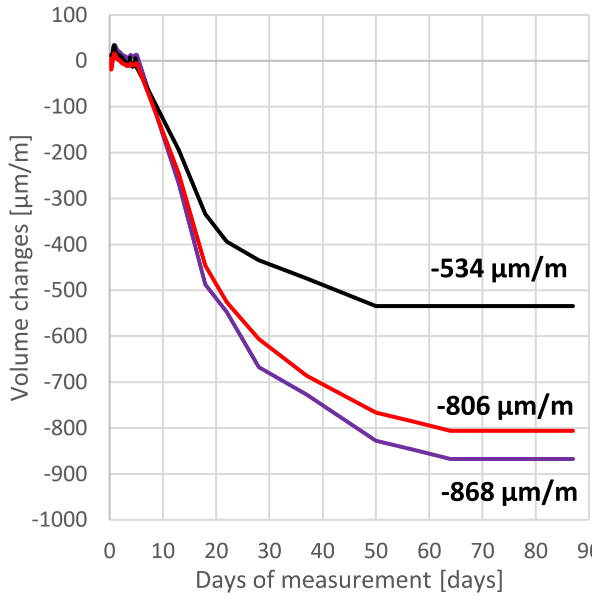

Fig. 4 – Comparison of volume changes of cement concrete specimens. Purple: Climate chamber + Laboratory; Black: Climate chamber + Outdoor environment; Red: Laboratory

4 Conclusion

The article provides relatively comprehensive information on the volume changes of Portland cements, which were tested using a shrinkage-drain. In terms of practical results can be observed variability between individual cements, but as well between specimens of the same cements. Certain differences between individual cements are understandable and it needs to say, that differences aren't very significant. Especially evaluating of shrinkage was very hard with regards to the stability of properties of cement in time and as well evaluating of the lowest shrinkage. Specimen's variability of the same cement is complex problem and it is certainly caused by interaction minor variations of chemical composition and fineness of grinding. Also, external influences like storage of specimens, differences during measuring and variable environment. The results of the experiment are unique because such extensive measurement of volume changes by shrinkage drain has not yet been performed. In particular, the results show that cements from different cement plants have minor variations in composition and material preparation. However, all tested cements meet the requirements of EN 197-1 [7] as Portland cements CEM I 42.5 R. When designing mortar of concrete, it is necessary to take into account the change of cement from another cement plant (even though it is the same specification) and it is also necessary to realize that even if the same boundary conditions are met, the different deliveries of cement affect the course of volume changes.

Values of volume changes the same cements in concrete are lower. One of the reasons is the use of grain aggregates and longer concrete curing that have been selected for 5 days. Volume changes on the same concrete have been tested under various conditions, and it is interesting to observe the difference between the laboratory and the real environment where the final shrinkage is lower. Measured values of volume changes in different environments using shrinkage-drain serve as a basis for calculation models, which will be the subject of further research where these values will be compared with calculations. This part of the experiment is also taken as the input part of the research, which will gradually measure the influence of the subsoil and sliding joints on the volume changes of the concrete. Measurement of concrete volume changes using a shrinkage-drain is important for determining volume changes and, in particular, final shrinkage in different environments, which further serves as a benchmark for different concrete in future experiments.

5 Acknowledgments

The work was supported by the VŠB-TUO Student grant competition. The project registration number is SP2018/153.

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