Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 195 (2017) 17 – 23

Procedia Engineering

www.elsevier.com/locate/procedia

18th International Conference on Rehabilitation and Reconstruction of Buildings 2016, CRRB 2016

Comparison of Measurements Methods Intended to Determination of the Shrinkage Development in Polymer Cement Mortars

Barbara Kucharczyková[a]*, Ondřej Karel[a], Petr Daněk[a], Dalibor Kocáb[a], Petr Pőssl[a]

[a]*Brno University of Technology, Faculty of Civil Engineering, Veveří 331/95, 602 00, Brno, Czech Republic*

Abstract

The paper deals with the experimental determination of the shrinkage progress of the polymer cement (PCC) mortars. The main motivation of performed measurements was to compare the results obtained from two different measurement procedures based on the measurement of the relative length changes and relative mass losses of the test specimens during whole time of ageing. Performed experimental analysis, focused on the determination of the progress of the relative length changes and relative mass losses, showed advantages and disadvantages of investigated measurement procedures. All performed measurements exhibited almost the same total progress of relative mass losses regardless of the used test procedure and size of specimens. The differences in the relative length changes originated from the capabilities, limitations and regulations of particular measurement procedures.

Peer-review under responsibility of the organizing committee of the 18th International Conference on Rehabilitation and Reconstruction of Buildings 2016

Keywords: Shrinkage, relative length change, PCC mortar, composite

1. Introduction

Experimental determination of the volume changes of composite materials of different compositions still remains in the focus of researchers, civil engineers as well as concrete producers. Advancement in technology and

* Barbara Kucharczyková. Tel.: +420-541-14-7527.
E-mail address: Barbara.Kucharczykova@vutbr.cz

Peer-review under responsibility of the organizing committee of the 18th International Conference on Rehabilitation and Reconstruction of Buildings 2016
doi:10.1016/j.proeng.2017.04.518

composition of building materials in turn requires advancement in test procedures used for the determination of physical and mechanical parameters of new materials, see e.g. [1,2].

The current approach in the field of material testing is aimed at identifying disruptions in the internal structure of structural elements as early as possible. This facilitates early diagnostics of the problem which allows relevant precautions preventing later decrease in durability of the building structure to be designed. Experience gained from measurements performed in recent years suggests the necessity of assessing the magnitude of shrinkage in two consecutive stages of composite material ageing – in the early stage of setting and hardening and during the long-term of composite materials ageing [3,4,5,6]. The early age measurements are able to identify the volume or length changes as well as initial micro-cracking due to initial solidification, moisture migration and micro-structure formation. The magnitude of these initial deformations, in some cases, can be very significant and can essentially affect the total progress and final value of material shrinkage [7]. Scientific sources provide a number of approaches to determine the value of concrete and mortars shrinkage [8,9,10]. However, these are mostly methods for separate determination of individual components of shrinkage in the early age – such as methods for determining plastic or autogenous shrinkage described e.g. in [4,9,11,12,13,14,15,16] and methods for determining the shrinkage due to drying defined mainly in the national standards of various countries. Contemporary approaches to concrete and mortars shrinkage measurement are based mainly on the determination of relative length changes. In most cases, measurement begins after removing specimens from their moulds, which is typically no sooner than after 24 hours of ageing. In important or complicated load-bearing structures, such as bridges, ceilings, or structures with complex form, shrinkage is measured directly on a structural element using a special type of wire strain gauge designed to be embedded in the concrete. Such gauges are typically tied to the reinforcement cage of the measured element by means of rebar extensions [17,18,19,20,21].

Guidelines reflecting the recent advances in theoretical and experimental research in the field of the creep and shrinkage of cement composites (especially concrete) have been published under RILEM TC-242-MDC (chair Zdeněk P. Bažant) [22].

In recent years, the method of acoustic emission (AE) has also been widely used as a supplemental measurement method for the non-destructive monitoring of the changes in the specimen’s internal structure during static and dynamic loading tests as well as for the monitoring of the behaviour of composite materials during setting and hardening [7,23,24]. The AE method is considered to be a "passive" non-destructive technique because it usually identifies defects as they develop during the test [25] and allows for monitoring of changes in the behaviour of materials over a long period of time and without moving any of its components. This, together with its ability to detect crack propagation occurring not only on the surface but also deep inside the material, makes the technique quite unique.

2. Experimental part

The experimental part was focused on determination of the shrinkage progress of the polymer cement (PCC) mortars. The main motivation of performed measurements was to compare the results obtained from two different measurement procedures based on the measurement of the length changes and mass losses of the test specimens during whole time of PCC mortars ageing.

The first measurement method used for the experiment is procedure described in the ČSN EN 12617-4 [26]. For the purpose of estimation of the influence of different curing conditions on the shrinkage progress, two sets of prismatic test specimens with dimensions of 40 × 40 × 160 mm were manufactured. The first set (Set 1) of specimens was cured according to the standard requirements [26] – after the fresh PCC mortar was placed into the mould, the top surface of the test specimens was protected from drying with PE foil for 24 hours. Than the specimens were demoulded and again coated with PE foil for another 48 hours. After this curing procedure was completed, the coating foil was removed and the test specimens were further exposed to the free drying for the entire time of the measurement. The relative length and mass losses measurement started 24 hours after specimens’ manufacturing. The second set (Set 2) was left in a mould for approx. 70 hours and the top surface was not protected from drying. After demoulding the specimens were left to dry freely during the entire time of their ageing. The relative length and mass losses measurement for Set 2 started approx. 70 hours after specimens’ manufacturing. In order to facilitate the measurement of relative length changes in the longitudinal axis of the test specimens, special markers were embedded into the ends of specimens. The moulds for specimens' manufacturing and test device used for length changes measurement is shown in Fig. 1. The relative length changes and relative mass losses were measured in regular intervals.

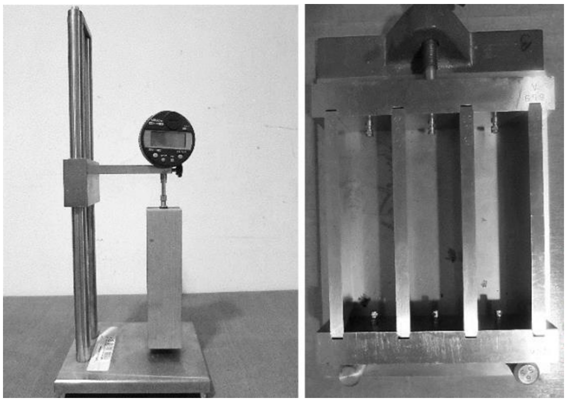


Fig. 1. Moulds and test device for measurement according to the ČSN EN 12617-4 [26]

The second measurement procedure used for the experiment uses measurement equipment standardized according to the Austrian standard OENORM B 3329:2009-06-01 [27]. This equipment – shrinkage moulds with dimensions of 100 × 60 × 1000 mm (Set 3) – is designed for shrinkage measurement especially in the early stage of composite materials setting and hardening. Special markers were designed at the Brno University of Technology (BUT) in order to facilitate the subsequent long-term measurement of relative deformations [28]. These markers were embedded into the upper surface of the PCC mortar placed in the shrinkage moulds. In this way, two gauging bases were created for the further measurement (Fig. 2). This arrangement enabled the capture of the total relative length changes of the composite since the time when the composite is placed into the mould until its long-term ageing after the specimen is removed from the shrinkage mould. The polyethylene foam mat (MIRELON) of 2 mm thickness was placed on the bottom and along both longitudinal sides of shrinkage moulds in order to ensure free movement of the specimen in the mould. The shrinkage moulds were filled with PCC mortar and placed onto a special weighing table [29] that allowed continuous recording of mass losses caused by free drying of the specimens' surfaces. The measurement was started half an hour after moulds' filling. The thermal sensor COMET was embedded at the end of shrinkage moulds in order to measure the temperature inside the specimens. The length change was continuously measured in the longitudinal axis of the specimens in the moulds within the first 70 hours of ageing. The top surface of the specimens was not protected from drying. The specimens were then extracted from the moulds and placed on the table. Further measurements were performed using a strain gauge which was fixed onto the embedded markers. The specimens were then left to dry freely for the entire time of the measurement and were measured and weighed at regular intervals. The final arrangement of measurement devices before starting the measurement is shown in Fig. 3.

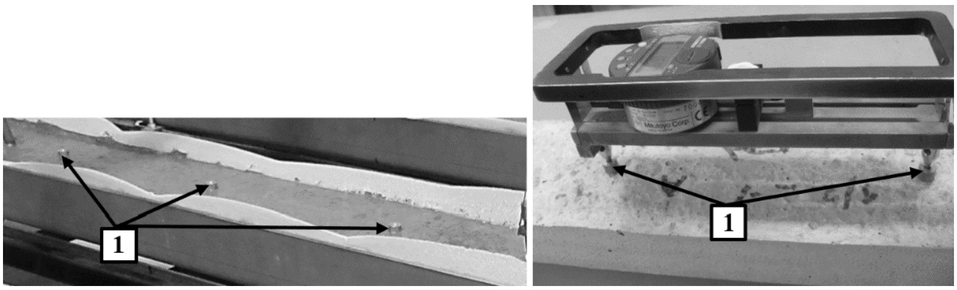


Fig. 2. Embedded markers for long-term measurement (1 – markers for long-term measurement)

All measurements were performed in a laboratory at a stable temperature of (21 ± 2) °C and relative humidity of (60 ± 10) %.

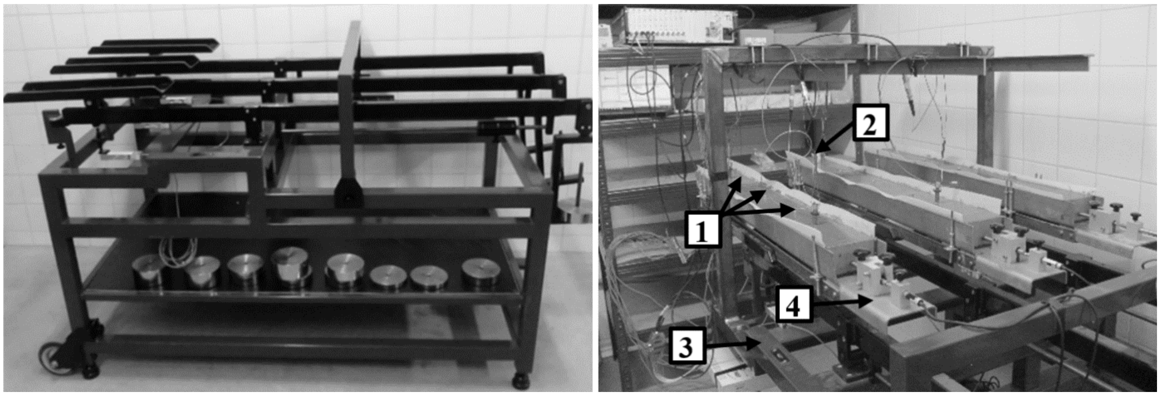
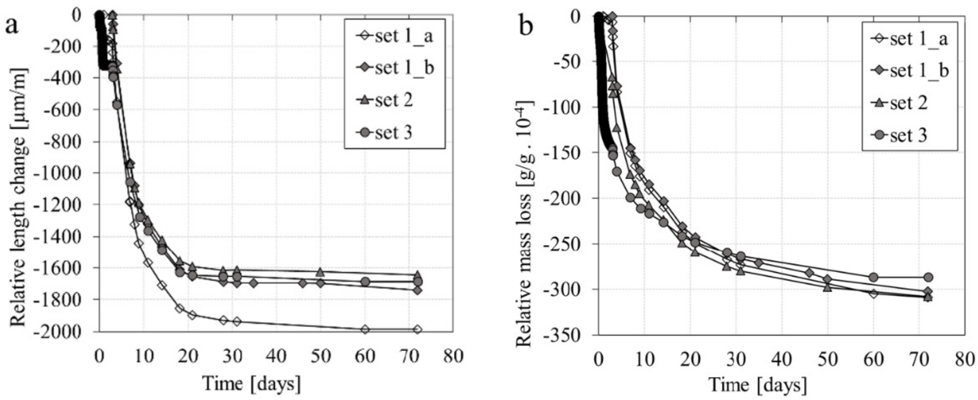


Fig. 3. Arrangement of measurement devices (1 – markers for long-term measurement; 2 – temperature probe; 3 – weighing table; 4 – shrinkage mould).

3. Results and discussion

The results of performed experiments are given in following figures. Fig. 4 shows progress of relative length changes (a) and relative mass loses (b) measured over the whole time of PCC mortars ageing. It should be noted that the Set 2 and Set 3 specimens were cured in the same way over whole time of measurement. The results for Set 1 were evaluated in two ways for purpose of results interpretation. In the first case, Set 1_a represents the real progress of investigated characteristics (including the initial measurement performed for specimens coated with the PE foil). In the second case, Set 1_b, the first part of measurement when the specimens were protected from drying was neglected and the evaluation started with the measurement performed after the PE foil was removed from the specimens. Apparently, both measurement procedures showed almost concurrent results. Fig. 4 (a) shows the progress of relative length changes determined for three sets of test specimens. The progress of deformation for Set 1_a is rather different – the final value of shrinkage is higher by approx. 300 μm/m than the final value of shrinkage of other sets of specimens. This difference probably originated from the initial curing and deformation recorded within the first 48 hours. In spite of the fact that the Set 1_a specimens were protected from drying, relative length change of approx. 200 μm/m was recorded. In case the initial measurement is neglected (Set 1_b) the progress as well as the final value of deformation is almost the same as in case of Set 2 and Set 3. The progress of relative mass losses (Fig. 4 b) was almost the same for all sets of specimens regardless of the test procedure and size of



specimens.

Fig. 4. (a) Progress of relative length changes and (b) relative mass losses measured over the whole time of composite's ageing.

Concerning the early age measurement (see Fig. 5 a), it can be stated that slight differences in the initial part of the progress of relative length changes can be observed. This differences originated from the measurement procedures used for measurement. In case the second procedure (the shrinkage moulds) was used (Set 3), the measurement started shortly after filling the moulds.

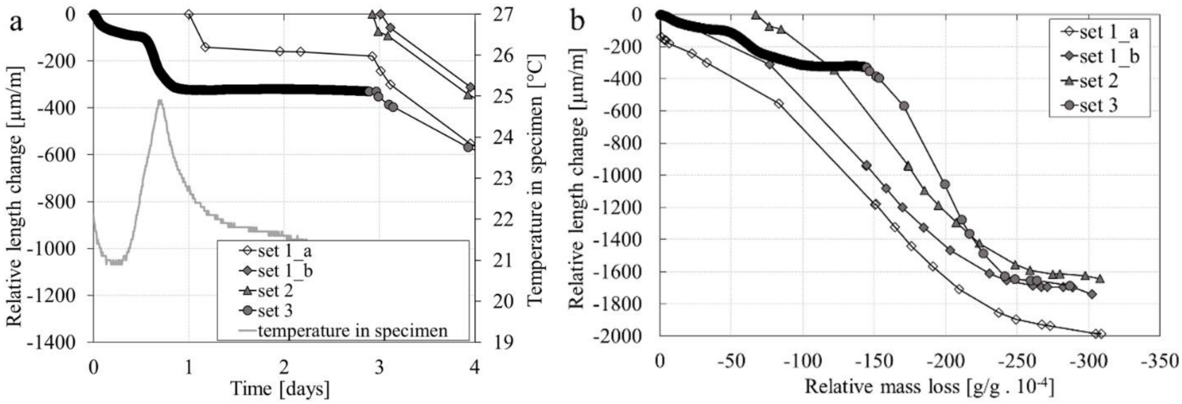


Fig. 5. (a) Progress of relative length changes and temperature measured inside the test specimen; (b) Relationship between the relative length changes and relative mass losses.

Therefore, very early deformations caused by initial solidification, water migration and temperature development, were recorded. The progress of relative length changes corresponds well to the progress of temperature measured inside the specimens. Also the setting times can be estimated from this measurement. The first measurement method is not able to capture this initial deformation because the measurement started after 24 hours of mortar ageing. The differences in the test procedures are well presented in the relationship between relative length changes (ε) and relative mass losses (m) measured over the whole time of specimens ageing (see Fig. 5 b). The start of measurement as well as curing conditions are very well reflected in the $\varepsilon - m$ curve. Fig. 5 b shows that the progress of the $\varepsilon - m$ curves determined for Set 1_b and Set 3 are almost the same at the beginning and at the end of measurements. The progress of the middle part of the curve for Set 3 is affected by the following initial curing conditions – the specimens were placed in the shrinkage moulds up to 70 hours of specimens' ageing, only the top surface was exposed to free drying. This progress in this middle part of the curve corresponds well to the progress recorded for the Set 2 specimens cured in the same conditions. If the specimens were extracted from the shrinkage moulds earlier, the progress of the $\varepsilon - m$ curve would correspond closer to the progress of the $\varepsilon - m$ curve determined for the Set 1_b. The progress of $\varepsilon - m$ curve of Set 1_a is again influenced by protection from drying for 72 hours.

4. Conclusion

The performed experimental analysis, which focused on the determination of the progress of the relative length changes and relative mass losses, showed advantages and disadvantages of investigated measurement procedures. All performed measurements exhibited almost the same total progress of relative mass losses regardless of the test procedure and size of specimens. The differences in the relative length changes originated from the capabilities, limitations and regulations of particular measurement procedures. The main advantage of the first method is the fact that the test procedure is standardized and all objects (testing laboratories) which specialize in the PCC mortars can use it for the conformity attestation. Nevertheless, there are some limitations which do not allow the measurements within first 24 hours of material ageing. The main advantage of the second measurement procedure is the ability to capture the initial length changes and relative mass losses which take place in the very early stage of PCC mortars ageing. The second procedure is also more adaptive and can be adjusted to the specific requirements according to the tested materials and curing conditions. The simultaneous measurement of temperature progress and internal structure changes are other procedure's benefits for the results evaluation and interpretation. The main disadvantages of this procedure are relatively high purchase cost and manipulation with moulds and test specimens because of their dimensions and weight.

Acknowledgements

This outcome has been achieved with the financial support of the standard specific research program at Brno University of Technology, project No. FAST-S-16-3125.

References

[1] ČÍTEK, D., RYDVAL, M., KOLÍSKO, J. Volumetric Changes of the UHPC Matrix and its Determination. Applied Mechanics and Materials, 2016, 827, 215-218.
[2] KONG, X., ZHANG, Z., LU, Z. Effect of pre-soaked superabsorbent polymer on shrinkage of high-strength concrete. Materials and Structures, 2015, **48**(9), 2741-2758.
[3] TOPOLÁŘ, L., MISÁK, P., KOCÁB, D., MATYSIK, M. Applying Method of Acoustic Emission for Monitoring of Different Concrete Mixture during Setting and Hardening. Solid State Phenomena, 2016, 249, 91-95.
[4] HOLT, E. E. Early age autogenous shrinkage of concrete. Espoo: Technical Research Centre of Finland, 2001, 184 p. + app. 9p, ISBN 95-138-5870-7, VTT Publications 446, Technical Research Centre of Finland.
[5] HAVLÁSEK, P. *Creep and Shrinkage of Concrete subjected to variable Environmental Conditions*. Prague, 2014. PhD Thesis. CTU, Faculty of Civil Engineering. Vedoucí práce Jirásek Milan.
[6] RILEM draft recommendation: TC-242-MDC multi-decade creep and shrinkage of concrete. *Materials and Structures*. 2015, **48**(4), 753-770.
[7] TOPOLÁŘ, L., PAZDERA, L. Acoustic Emission in Protected and Non-Protected Concrete During the First 24 Hours. Applied Mechanics and Materials, 2014, **578-579**, 1149-1152.
[8] NEWMAN, J., CHOO, B.S. Advanced concrete technology: Concrete properties. Amsterdam: Elsevier, 2003, ISBN 07-506-5104-0.
[9] Schleibinger Testing Systems. Available: http://www.schleibinger.com.
[10] REINHARDT, H.W., GROSSE, C.U. Advanced testing of cement based materials during setting and hardening. Bagneux, France: RILEM Publications, 2005, 341 s. ISBN 29-121-4381-0.
[11] PCA: The Portland Cement Association. Available: http://www.cement.org.
[12] KRATOCHVÍL, M., KADLEC, M., TERZIJSKI, I., ZVOLÁNEK, L. Autogenous Shrinkage and its Measurement since the Moment of Concrete Casting. (Autogenní smršťování a jeho měření od okamžiku uložení betonu). Beton: Technologie, konstrukce, sanace. Praha: Czech Concrete Society, 2014, 14(3), 64-67. ISSN 1213-3116 (in Czech).
[13] BARCELO, L., MORANVILLE, M., CLAVAUD, B. Autogenous shrinkage of concrete: a balance between autogenous swelling and self-desiccation. Cement and Concrete Research , 2005, 35(1), 177-183.
[14] SOLIMAN, A. M., NEHDI, M. L. Effect of drying conditions on autogenous shrinkage in ultra-high performance concrete at early-age. Materials and Structures, 2011, 44(5), 879-899.
[15] MAZZOLI, A., MONOSI, S., PLESCIA, E. S. Evaluation of the early-age-shrinkage of Fiber Reinforced Concrete (FRC) using image analysis methods. Construction and Building Materials, 2015, 101, 596-601.
[16] ZHANG, J., GAO, Y., HAN, Y., WANG, J. Evaluation of Shrinkage induced Cracking in Early Age Concrete: From Ring Test to Circular Column. International Journal of Damage Mechanics. 2015. ISSN 10567895.
[17] NORISHAM, I., OMENZETTER, P., LIPSCOMBE, P. Monitoring system for in-situ measurement of creep and shrinkage effects in a prestressed concrete bridge. In: 20th Australasian Conference on the Mechanics of Structures and Materials, Toowoomba, Australia, 2008, s. 767-771.
[18] Creep, shrinkage and durability mechanics of concrete and concrete structures proceedings of the eighth International Conference on Creep, Shrinkage and Durability of Concrete and Concrete Structures, Ise-Shima, Japan, 30 September-2 October 2008. Boca Raton: CRC Press, 2009. Edited by Sato, R., Maekawa , K., Tanabe , T., Sakata , K., Nakamura , H., Mihashi, H.: Taylor & Francis 2008. ISBN 9780203882955.
[19] STRÁSKÝ, J., ZICH, M., NOVOTNÝ, P. Bridges with Progressivelly Erected Decks. In: CIV - SPRING 2014. Calgary, 2014, s. 19-22.
[20] ZICH, M. The Concept of a Long-Term Monitoring of Highway D47 Bridges (Koncepce dlouhodobého sledování mostů na dálnici D47). Beton: Technologie, konstrukce, sanace. Prague: Czech Concrete Society, 2011, 11(4). ISSN 1213-3116. (in Czech)
[21] HOFÍREK, R. a M. ZICH R35 Sedlice - R35 Sedlice - Opatovice, Construction of the Flyover SO 206.2 – Monitoring of the Stress in the Load Bearing Structure (Opatovice, dostavba estakády SO 206.2 - sledování napjatosti nosné konstrukce). In: 22nd Concrete Days 2015: Conference proceedings. Czech Concrete Society ČSSI, 2015. ISBN 978-80-906097-0-9. (in Czech)
[22] RILEM draft recommendation: TC-242-MDC multi-decade creep and shrinkage of concrete. Materials and Structures, 2015, 48(4), 753-770.

[23] CARPINTERI, A., LACIDOGNA, G., NICCOLINI, G., PUZZI, S. Critical defect size distributions in concrete structures detected by the acoustic emission technique. Meccanica. 2008, 43(3), 349-363. Available: http://link.springer.com/10.1007/s11012-007-9101-7.
[24] TOPOLÁŘ, L., TIMČAKOVÁ, K., MISÁK, P. Influence of Superplasticizer Quantity on Formation of Micro-Cracks during Setting and Hardening of Concretes by Acoustic Emission Method. Advanced Materials Research, 2015, (1124), 219-224.
[25] GROSSE, Ch. U., OHTSU, M. Acoustic emission testing. 1 st ed. New York: Springer, 2008. ISBN 9783540699729.
[26] ČSN EN 12617-4. Products and systems for the protection and repair of concrete structures - Test methods - Part 4: Determination of shrinkage and expansion. Prague: ČNI, 2003. (in Czech). This standard is the Czech version of the European Standard EN 12617-4.
[27] OENORM B 3329:2009-06-01. Grout - Requirements and test methods. Austria, 2009.
[28] KUCHARCZYKOVÁ, B., DANĚK, P., MISÁK, P., VYMAZAL, T. Apparatus for measuring relative deformation of concrete and cement composites. 2011. Czech Republic. CZ 21600 U1 Utility model. Applied 13.10.2010. Granted 12.1.2011. Entered 3.1.2011. Available: https://isdv.upv.cz/webapp/webapp.pta.detail.
[29] VYMAZAL, T., DANĚK, P., KUCHARCZYKOVÁ, B., MISÁK, P. Continuous measurement method of cement composite weight losses in early phase of setting and hardening, and apparatus for making the same. 2015. Czech Republic. CZ 304898 B6 Patent. CZ 304898 B6 Patent. Granted 26.11.2014. Entered 7.1.2015. Available: https://isdv.upv.cz/webapp/webapp.pta.detail