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**DOI**
10.1007/978-3-031-07746-3_32

**Publication date**
2022

**Document Version**
Final published version

**Published in**
SSCS 2022

**Citation (APA)**
Schlangen, E., Liang, M., & Savija, B. (2022). The Influence of Autogenous Shrinkage and Creep on the Risk of Early Age Cracking. In P. Rossi, & J.-L. Tailhan (Eds.), *SSCS 2022: Numerical Modeling Strategies for Sustainable Concrete Structures* (pp. 327-334). (RILEM Bookseries; Vol. 38). Springer. https://doi.org/10.1007/978-3-031-07746-3_32

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# The Influence of Autogenous Shrinkage and Creep on the Risk of Early Age Cracking

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**Abstract.** The study aims to investigate the mechanism of early-age cracks in different massive concrete structures (i.e. tunnels, bridge foundations and underground parking garages), with the objective of answering the following three specific questions:

1) How does the parameters of concrete proportion mix (e.g. w/c ratio, cementitious materials, aggregates, etc.) influence the formation of autogenous shrinkage and creep, especially at early age with the focus on the first 24 h?
2) How to build theoretical and numerical model for the process of early-age crack formation and then quantify the damage status of concrete materials?
3) How to link the results derived from material scale to structural scale, and provide useful reference for practical engineering projects?

To study the basic mechanism a research program is performed in which different mixes are tested in a Temperature and Stress Testing Machine (TSTM). Furthermore autogenous shrinkage is measured in different ways. Modeling with a FEM-tool is used to predict the risk of early age cracking. The results indicate that the combined shrinkage (or expansion and the relaxation (or creep) during the first hours of hydration have a huge influence on the stresses that develop later and with that are important to determine the risk of cracking in massive concrete structures. Since investigating the stresses that built up in the first hours after casting in such a TSTM is rather difficult, we designed a new version of the TSTM machine in which dog bone specimens are tested vertically in a Universal Testing Machine (Instron).

**Keywords:** Early age cracking · Autogenous shrinkage · Creep · Concrete

## 1 Introduction

### 1.1 Problem Description

Early age cracking in concrete is a well-known problem. Imposed deformation due to heat of hydration and autogenous shrinkage develops during the hydration phase of the concrete. The mechanical properties like stiffness, strength and visco-elastic behavior is gradually increasing with hydration. When the imposed deformation is restrained stresses in the material will develop and if too high cracks will occur. In Fig. 1 a typical

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P. Rossi and J.-L. Tailhan (Eds.): SSCS 2022, RILEM Bookseries 38, pp. 327–334, 2023.
https://doi.org/10.1007/978-3-031-07746-3_32

example of vertical early age cracks in a wall-slab connection are shown. These cracks typically start a short distance above the floor and propagate a few meters up. These are cracks through the complete cross section and when it is a water retaining structure, leakage is often the consequence. The cracks occur typically one or two weeks after casting when the structure is cooling down and shrinking.

**Fig. 1.** Water leakage through vertical early age cracks in a wall-slab connection.

The cracking is influenced by many parameters like mix-design and early age properties, temperature of the fresh mix, environmental conditions, dimensions of the structure and restraining conditions. A lot of research has been performed on this topic already and a very good summary is given in a state of the art report by Rilem [1]. Furthermore various simulation tools are available (also described in [1]) that are used for research purposes but also for engineering and designing measures to prevent this kind of cracking in practice. The success of these simulation and design tools depends to a large extent as always on the input parameters. Many properties of the material are needed and these properties are influenced by the condition the material is in. Generally all the properties are related to the degree of hydration of the material or a maturity concept is used in which the time is influenced by temperature.

### 1.2 Initial Lab Research

In the work of Van Bokhorst [2] an initial study of combined experimental and numerical research is performed to investigate especially the influence of autogenous shrinkage and creep during the first day on the risk of early age cracking. For a concrete mix that was going to be used for tunnel segments various properties were tested. The compressive strength and splitting tensile strength were determined at 1, 2, 5, 8, 14 and 28 days. Next to that the adiabatic heat development and the autogenous shrinkage was measured and a test was performed in the TSTM-machine at TU-Delft, see Fig. 2. In this test a dog-bone sample is cast in the machine with the chosen concrete mix. A temperature regime is applied which is expected to happen in the application in the tunnel. For this water with the desired temperature is circulated through the mold. The deformation of the dog-bone specimen is restrained by the machine by measuring with LVDT's the length (750 mm) of the straight part the dog-bone and keeping that zero by continuous adjusting the load in a closed loop system.

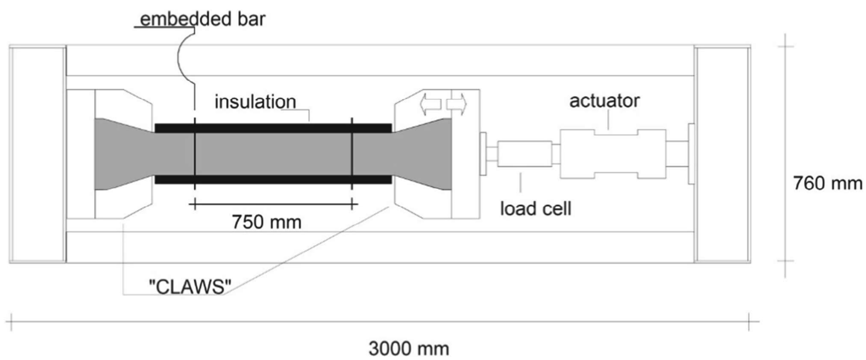


**Fig. 2.** A sketch of the TSTM-machine at TU-Delft.

### 1.3 Modelling with FEM-Tool

Modelling of the tunnel segment (wall-slab connection) was performed with MLS of femmasse [3]. This is a EM-based software tool specially designed to perform simulations to determine the risk of cracking. It is based on the state parameter concept in which maturity is used to determine all the properties of the elements in the model, depending on time, temperature and location.

First the TSTM-experiment as discussed above is simulated. As input for the model the properties that are measured of the concrete are used. For properties that are not measured values recommended in Eurocode are adopted. Especially the early age creep or relaxation is an unknown parameter. By using the standard values for creep the results that were obtained from the simulations were very different from the experimental outcome. Then it was decided to fit the input for the creep (modelled with Maxwell chains) in such a way that a good match between the simulations and the TSTM test was obtained.

With these values the tunnel segment was simulated. The results are shown in Fig. 3. The cross section of the structure is given in which the stresses perpendicular to the cross section are shown that occur after cooling down of the wall. In the graph the (tensile) strength development is given as well as a line for 0.85 and 0. Times the strength. Values that are often used in design. The development of the tensile stress is given for the situation in which the creep is according to the Eurocode (grey line) and for the fitted creep data from the TSTM-test (black line). It can be clearly seen that with the fitted data a much higher tensile stress will occur in the cross section with a much higher risk of cracking.

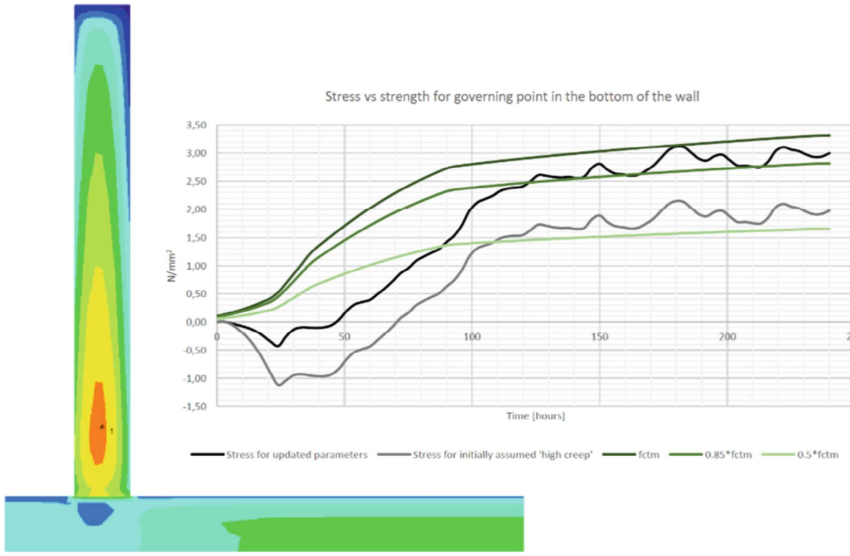


**Fig. 3.** Simulation of a wall to slab connection in a tunnel section. Stress profile after cooling down of the structure and stress and strength development in the core of the wall where the highest stress occurs.

### 1.4 Research Objective

The conclusion from this initial study [2] is that especially the early age creep or relaxation combined with the autogenous shrinkage in the first hours or day of hydration is extremely important for the stresses that will occur such structures. In contrary the measurement of creep and the autogenous shrinkage in the first hours or day is very difficult and results depend a lot on the set-up and conditions that are used for the measurements. Therefore it was decided to start a more detailed study to investigate these parameters.

## 2 Extended Lab Research

In the extended lab research we started with testing four different concrete mixes as explained in Table 1. The mixes are composed of CEMM III/B cement with different water to cement ratio (0.5, 0.42 and 0.35) and one mix with CEM I with w/c of 0.42.

These mixes (Table 1) were tested in the TSTM machine at 20 C and with restrained deformation and in the ADTM machine in which a prism is casted and the autogenous deformation is measured. Furthermore the strength development is followed (see Fig. 4) to have the basic properties. In the ADTM and TSTM tests the measurements and control cannot be started immediately after the concrete is casted, since a steel pin is placed inside the concrete to which the LVDT’s are attached. For this the concrete needs some stiffness. The measurement of autogenous deformation and the control of deformation in the TSTM test therefore starts after 7 h. To check the autogenous shrinkage of the cement paste mixtures that are used in the concretes, the autogenous deformation is measured in standard corrugated tubes test measurements [4].

**Table 1.** Concrete mixes used

| | W/C | Cement | Water | Sand (0–4 mm) | Gravel (4–16 mm) | SP |
|---|---|---|---|---|---|---|
| Mix 1 | **0.50** | 320 (CEM III/B) | 160 | 811.8 | 1032 | 0 |
| Mix 2 | **0.42** | 320 (CEM III/B) | 134.4 | 811.8 | 1032 | 0.475 |
| Mix 3 | **0.35** | 320 (CEM III/B) | 112 | 811.8 | 1032 | 1.9 |
| Mix 4 | **0.42** | 320 (CEM I) | 134.4 | 811.8 | 1032 | 0 |

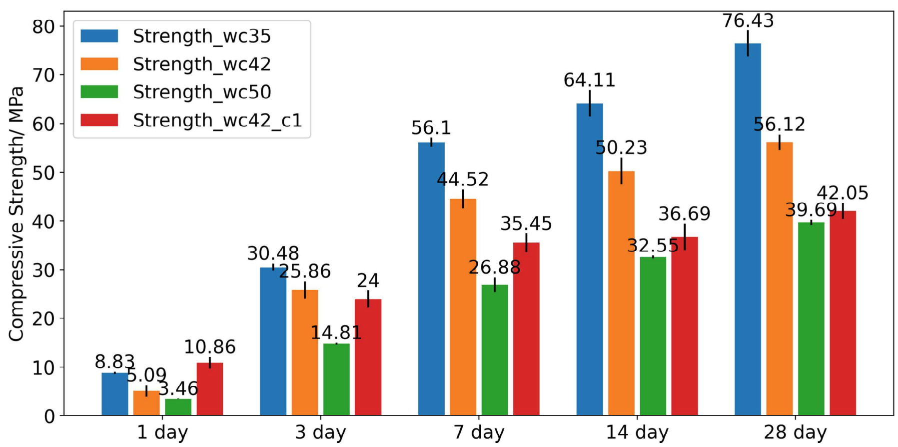


**Fig. 4.** Strength development of 4 concrete mixes.

## 3 Obtained Results

The results obtained from the ADTM tests for measuring the autogenous shrinkage on the 4 concrete mixtures is shown in Fig. 5. The temperature in all specimens is kept to 20 C all the time. However some variation in the beginning of max ±.5 C is observed due to hydration heat because the control with running water through the moulds is not that fast. Note that all mixes first show and autogenous expansion after which a shrinkage starts. The results seems not very consistent. Only the amount of shrinkage in the material with the lowest w/c is the highest, which is expected.

In Fig. 6 the stress that develops in the TSTM machine in which the deformation of the dogbone specimens are restrained is plotted for the 4 mixes. The tensile stress development of the mix with w/c of 0.35 is clearly the highest. In Fig. 7 the aoutonous shrinkage measured on the pastes is shown. These results are consistent with the measurements on the concrete, except that the expansion part is far smaller.

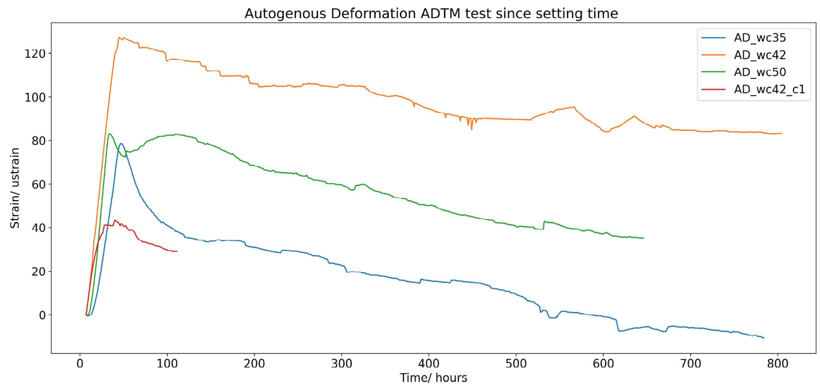


**Fig. 5.** Autogenous shrinkage of 4 concrete mixes.

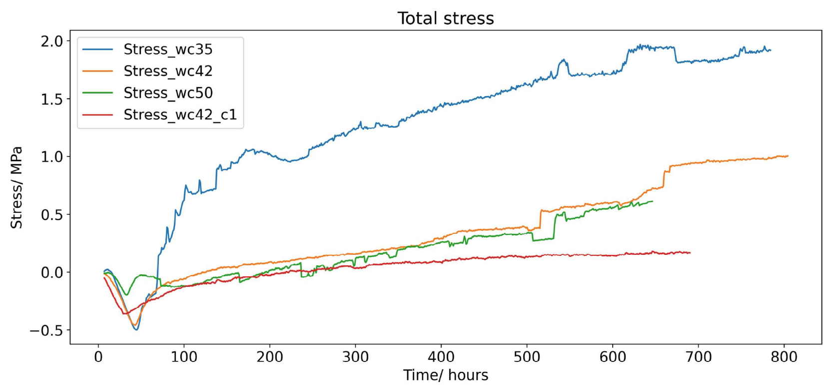


**Fig. 6.** Stress building up in restrained specimens in TSTM due to autogenous shrinkage for the 4 concrete mixes.

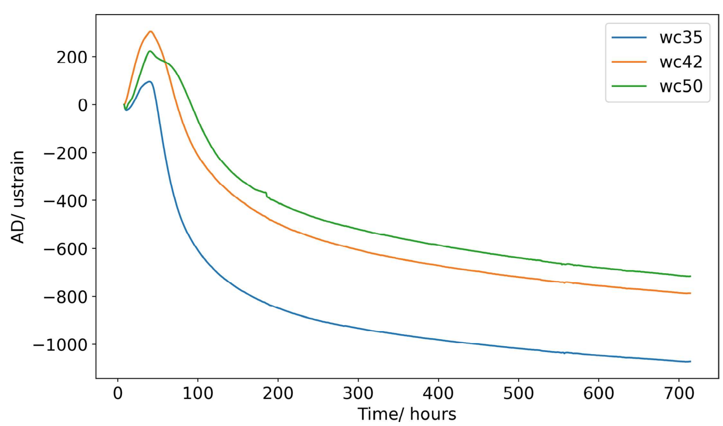


**Fig. 7.** Autogenous shrinkage measured in corrugated tube tests for 3 mixes with CEM III/B cement.

It is however difficult to dervive strong conclusions from these measurements. It has to be kept in mind that the measurements in ADTM and TSTM do not start immediately after casting. A second point is the temperature control in the mould, which is not extremely accurate. And finally there will be some friction between mould and concrete specimen which will influence deformation of the specimen and also the stresses that develop.

## 4 Design of New Set-Up

In order to obtain more accurate measurements of the shrinkage and stresses that develop in the material, especially at early age a new TSTM setup was designed. In this setup the specimen will be vertical to reduce frictional effects and the temperature control will be much faster. Furthermore the specimens will be smaller which also enables faster control of the surface temperature and reduction of the gradients. The setup will be placed inside a Universal Testing Machine (Instron) and active control of deformations can be done from time zero, immediately after casting, since contactless measurements of deformations will be done.

At the moment of writing this article the set-up is still in testing phase. The first results look promising (Fig. 8).

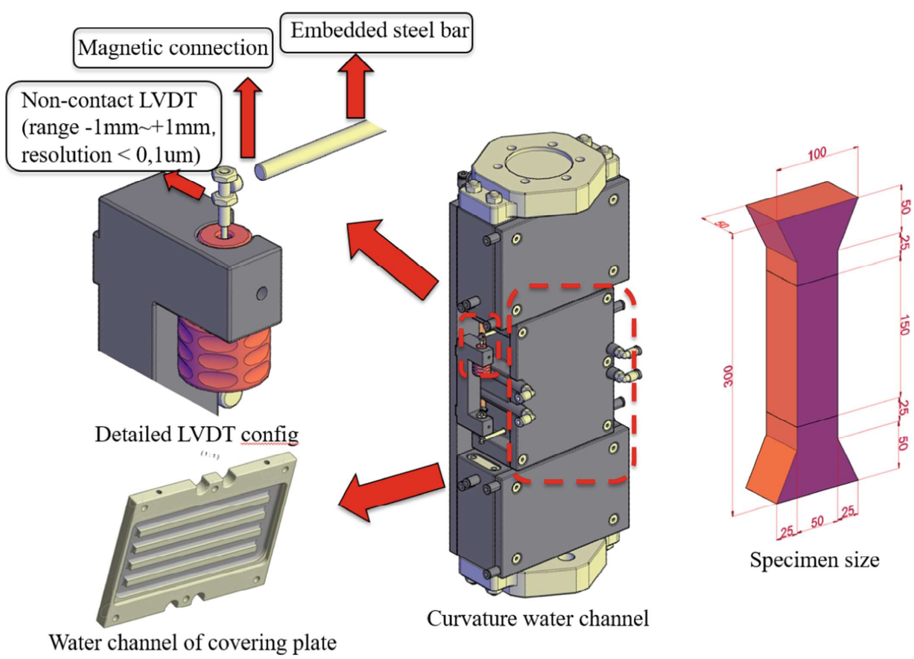


**Fig. 8.** New design of TSTM set-up.

## 5 Conclusions

This paper presents a combination of experimental and numerical research to study the effect of autogenous deformation on the stresses that develop in a restrained situation in early age concrete.

The results show that assumed (or measured) autogenous shrinkage and creep (or relaxation), especially during first day have an enormous effect on the stresses that develop in a real structure.

For regular concretes we can still rely to some extent on experience for estimating the material properties. However, we are moving more towards alterrnative concretes like alkali activated materials using waste materials and also the use recycled aggregates in concrete becomes a standard. These materials are known to have autogenous shrinkage and also the visco-elastic behaviour is different from what we are used to with regular concrete. Having accurate material properties to feed modelling will then be crucial to predict the risk of cracking.

The measurement of the shrinkage and creep is however quite complicated due to various effects: exact temperature control, time to start the measurement, and friction between mould and specimen.

A new TSTM setup is designed which could prevent the measurement errors.

In the continuation of this research project the new set-up will be tested and results will be used to predict stresses in early age concrete structures. Furthermore the input will be used in combination with ongoing machine learning approaches [4, 5] to better understand the influence of shrinkage and creep effects at early ages.

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