CHAPTER 1 - INTRODUCTION

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1.1. SUBJECT MATTER

An important aspect of curing that is sometimes forgotten is that curing is carried out not only to promote hydration, but also to minimize shrinkage. The means and methods for mitigating shrinkage and cracking of early-age concrete include cement modification, mineral additives, chemical admixtures, fibers, and control of curing conditions. Novel methods of shrinkage mitigation, based on special advanced methods of internal curing (IC), are currently being intensively studied in research groups in several countries. They are the focus of this report.

Advances in concrete technology over the past several years have led to the practical use of concrete with a low water-binder ratio (w/b). Unfortunately, concretes with low w/b are prone to early age cracking unless special precautions are taken. Because these mixtures have relatively low water contents and, therefore, less drying shrinkage, experts have had to look elsewhere for an explanation. During the past two decades, attention has focused on a phenomenon known as autogenous shrinkage. As the use of high-strength/high-performance concrete with low w/b has become more prevalent, some novel techniques to combat this phenomenon have been developed.

In general, autogenous shrinkage is a phenomenon, which is ingrained in concrete of low w/b ratio. Autogenous shrinkage may be considered the "Achilles' hill" of high-strength/high-performance concrete (HSC/HPC) [1]. It is not caused by external influences, such as moisture loss or temperature change, but is the result of chemical shrinkage, which cannot be avoided. It occurs because the absolute volume of the hydrated cement products is less than the volume of the cement and water before hydration.

In low water/binder ratio matrices chemical shrinkage leads to considerable self-desiccation. This self-desiccation results in the development of capillary stresses causing autogenous shrinkage. This process occurs over several days or weeks, with the major portion occurring within the first day or two of hardening.

Autogenous shrinkage is normally insignificant in concrete with a w/b greater than about 0.4. As w/b is reduced, however, autogenous shrinkage tends to increase and can even become a dominant factor. In fact, in concrete with a w/b of 0.30, autogenous shrinkage can represent approximately half the total shrinkage.
Mineral additives can significantly increase autogenous shrinkage. The early occurrence of autogenous shrinkage puts concrete at risk for cracking: in this period the tensile strain capacity is at a minimum and the concrete elements will be subject to the effects of high temperature differentials.

Conventional curing procedures, such as ponding in water, are not sufficiently effective to combat autogenous shrinkage in low w/b concrete. They may eliminate the autogenous shrinkage in small cross-sections only, because the penetration of water from the externally ponded surface is limited.

In view of these limitations, different strategies have been developed in recent years, based on internal curing of concrete. These strategies, which have been investigated extensively in the last years, are aimed at mitigating self-desiccation and autogenous shrinkage. At the same time, the long-term (drying) shrinkage may increase, which must be taken into account, when an optimum curing technology is searched.

1.2. SCOPE AND LIMITATION OF WORK

Researchers in different countries around the world are presently on their way to develop practical solutions for different aspects of advanced methods of curing. The aim of this report is to assemble the various pieces of knowledge generated and to ultimately produce a general guide to assist concrete technologists.

The main objectives of the RILEM Technical Committee TC-196 ICC “Internal Curing of Concrete” are

1) to coordinate research efforts and compile the results of studying fundamental mechanisms responsible for internal curing, and

2) to develop practical recommendations for utilization of advanced methods of internal curing of concrete. These recommendations should include mainly technological procedures (preparation of raw materials, mixing, casting, vibration and curing) and concrete mix design (optimization of the type, dosage and properties of the water-deliberating phases). The geometry of cast and cured concrete elements has to be taken into account, as well as environmental conditions and using conventional curing agents. Numerous interacting phenomena such as shrinkage, creep, thermal effects, cracking, and interface quality should be investigated and addressed.

The focus of the current report is on internal curing of high-strength/high-performance concretes with low w/b ratio, in order to counteract their autogenous shrinkage caused by self-desiccation. As was mentioned before, autogenous shrinkage is a phenomenon ingrained in HSC/HPC of low water/binder ratio matrix. It is shown that autogenous shrinkage and shrinkage-induced cracking of concrete at early ages can be successively mitigated through internal curing.

Another important volume change mechanism at early ages is thermal dilation. This is an additional driving force of cracking in hardening concrete structures. Thermal dilation is higher in HSC/HPC, because the hydration-generated temperature rise becomes higher due to a higher binder content. Reliable test methods are needed in order to develop useful material models and to establish a better fundamental understanding of the two main volume change mechanisms. This is the basis for further development of durable HSC/HPC.

The report does not address all the early age problems. In reality, autogenous shrinkage cannot be completely isolated from other concurrent effects occurring in situ, such as loading.
of concrete structure and changing of environmental (thermal and hygral) conditions of concrete and the ambient media. The ideal design of concrete structures and choosing the proper technology of manufacture, curing and maintenance should address the whole problem, including the generation of thermal stresses, drying shrinkage and its coupling with autogenous shrinkage deformation, creep and relaxation of concrete under gradually increasing stresses under restraint as well as size effect. At the same time, thermal stresses, drying shrinkage, creep and other concurrent effects are not the central issues the report is focusing on. The current State-of-the-Art report is focused on how the internal curing technology and be used to mitigate autogenous shrinkage and - to lesser extent - shrinkage-induced cracking by means of internal curing technologies.

The fundamental mechanisms of internal water curing, including availability of the stored water in the particles of the IC agent are presented and analysed. It is shown that Powers’ model (slightly modified and reinterpreted in order to describe self-desiccation with the simplified concepts of capillary and gel water) allows estimating how much internal curing water is needed to prevent self-desiccation.

The experimental methods to observe and study internal curing of concrete, ranging from the most direct and to the most remote, are reviewed.

The report presents also a review of the application of computational modeling to understanding issues relevant to and predicting performance of systems with internal water curing. Model results are compared to available experimental data and supported by fundamental theories and mechanisms.

Internal curing, as well as external curing, can be classified into two categories:

- Internal water curing (sometimes called “water entrainment”), when the curing agent performs as a water reservoir, which gradually releases water, and
- Internal sealing, when the curing agent is intended to delay or prevent loss of water from the hardening concrete.

The committee addressed both kinds of internal curing, but focuses on internal water curing, which is much more known and developed than the internal sealing techniques.

Among different methods of internal water curing, those based on using pre-saturated light-weight aggregates (LWA) and super-absorbent polymers (SAP) are discussed in the report in more detail, than some other methods, which in the meantime are under development and feasibility study in research labs. A comparative analysis of different IC technologies is a part of the report.

Finally, the benefits and case studies using internal curing of concrete are presented.

REFERENCE