PERFORMANCE-BASED SPECIFICATION AND CONTROL OF DURABILITY OF REINFORCED CONCRETE STRUCTURES

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Abstract
Service life and durability of reinforced concrete structures depend primarily on the penetrability and thickness of the concrete cover. Currently, durability specifications in most Codes and Standards are based mainly on establishing constraints to the proportions of the concrete as function of the severity of the exposure. This approach ignores, to a large extent, the different performance of the different cement types and of the mineral components added to the cements or to the concrete itself, as well as the influences of on-site practice during the construction process.

Previous work of RILEM TCs has identified suitable test methods to measure the penetrability of the concrete cover, concluding that today there are several suitable devices on the market, with which site measurements (non-destructively or applied on drilled cores) of the penetrability and thickness of the concrete cover can be performed with sufficient accuracy. Based on this, the paper introduces a proposal for future work aiming at developing guidelines on how to apply those methods in practice for the performance-based specification of durability and for checking the compliance of the final product with the specification.

Keywords
Durability; Concrete cover; Permeability; NDT

1. INTRODUCTION
In reinforced concrete structures, deterioration is often associated with ingress of aggressive agents from the exterior and the near-surface concrete quality largely controls durability. The problem for engineers and concrete producers is how to provide adequate protection to the steel reinforcement by the cover layer, which is subjected to the action of
aggressive agents such as chloride ions or acidification from the surrounding environment. What is therefore required is the ability to quantify the quality of the cover layer in terms of engineering parameters that can immediately be useful to designers and concrete practitioners. These quantifiable parameters can then form the basis for crafting performance-based specifications that should help improve overall quality of reinforced concrete construction. Approaches to include such performance-based durability specifications in national standards and/or construction practices, based on appropriate test methods, are being developed worldwide.

A performance-based approach to design and specification of concrete structures basically consists of the two main components of i) appropriate test methods and ii) appropriate interpretation of test results obtained.

Traditionally, concrete compressive strength has been used as an indicator of durability. However, strength is not an adequate indicator because the test does not account for construction processing variables such as placing, compaction and curing. These affect the quality of the surface zone of the concrete and therefore have a direct influence on durability by controlling the movement of aggressive agents from the environment into the concrete. The important rate-controlling factors of concrete deterioration are therefore the concrete material constituents, the near-surface quality of the finished concrete and the aggressiveness of the environment. Durability specifications increasingly rely on measurement of the transport properties of the surface or cover zone of the concrete. These developments are paving the way for innovative durability design and performance specifications. For the particular but significant case of steel corrosion, the service life of the member depends also on the thickness of the concrete cover.

Many engineers are beginning to realise the benefits of moving away from prescriptive to performance-based specifications that will truly assist in improving concrete performance [1, 2]. Although the general philosophy of performance-based specifications is clear, there remains divergence on the appropriate definition and reliable measurement of quality parameters.

2. CURRENT PERFORMANCE-BASED SPECIFICATION METHODS FOR CONCRETE DURABILITY

2.1 General

Approaches to include durability specifications in national standards and/or construction practices are being developed in many countries worldwide. In the following, approaches established in Switzerland and South Africa are briefly discussed. These approaches relate to research carried out by the authors and give an overview on current developments in the field of performance-based durability design.

2.2 The South African Durability Index Approach

The South African concrete industry has for some years made use of performance-based durability indicators, mainly as a means to develop adequate mix designs for special applications and for quality control of in-situ concrete construction. A “Durability Focus Group” is currently developing an approach for the specification of durability indicators, aiming at standard minimum requirements for concrete structures when durability is of...
concern. At this point in time, the South African durability indices can only be considered as guidelines and the process of establishing these in practice is still in development. The ultimate objective is to include a holistic durability design and specification approach in the National Code of Practice, making the entire subject of durability accessible for and understood by all interested parties.

The South African durability index (DI) tests comprise oxygen permeability, chloride conductivity and water sorptivity tests [3 - 6]. The durability indices obtained with these test methods have been related empirically to service life prediction models. Index values can be used as the input parameters of service life models, together with other variables such as steel cover and environmental class, in order to determine rational design life. Limiting index values can be used in construction specifications to provide the necessary concrete quality for a required life and environment. Thus, a framework has been put in place for a performance-based approach to both design and specification.

In the South African approach, ‘durability indexes’ are quantifiable physical or engineering parameters which characterise lab or in-situ concrete and are sensitive to material, processing, and environmental factors such as cement type, water: binder ratio, type and degree of curing, etc. The approach has progressed to the point that both rational durability design and performance-based durability specifications are being developed and in some cases applied in actual construction [7 - 9].

While these are positive developments for improving the quality of construction, the usefulness of the approach must ultimately be assessed by the actual performance of structures built using the indexes for quality control purposes. Long-term studies of performance have been initiated, and preliminary results are encouraging. If correlations between the index values and long-term performance are confirmed, index tests could be used to control concrete quality through specifying limits to index values at a suitable age. Index tests could then be used as criteria to assess construction quality, and as a basis for fair payment, at least with regard to this aspect of durability.

2.3 Durability specifications in Switzerland

Similar to the South African approach, concrete structures in Switzerland are increasingly designed and tested for durability characteristics. The new Swiss Standard SIA 261/1: 2003 on “Concrete Structures” [10] states in 2.4.3.1 that “In order to ensure the durability, various measures have in general to be taken, depending on the exposure class and the intended use, for example: […] the production of an impermeable cover concrete, according to Section 6.4.2”. And, in 6.4.2.2: “The impermeability of the cover concrete shall be checked by means of permeability tests (e.g. air permeability measurements) on the structure or on core samples taken from the structure”.

In the supplementary specifications of this new standard [11], some tests related to transport mechanisms in concrete are described. For chloride resistance, the standard suggests the use of the chloride migration test developed by Tang and Nilsson [12]. Air permeability kT is to be determined using the non-destructive technique developed by one of the authors [13, 14]. A sorptivity test, based on measuring the progressive weight gain of specimens/cores in contact with a few mm of water is also included.

Maximum limits for kT, as function of the exposure class, have been proposed [15] and are being implemented in projects owned by the Swiss Federal DoT.
3. NON-DESTRUCTIVE EVALUATION OF THE CONCRETE COVER – CONCLUSIONS DRAWN FROM RILEM TC 189-NEC

As stated above, the reliable measurement of quality parameters is one of the most important prerequisites for successful performance-based durability design. In 2007, various research institutes and members of the industry from Europe, North America, and South Africa successfully completed a joint research project on the quality of concrete cover, concentrating their efforts in RILEM Technical Committee 189-NEC (Non-destructive Evaluation of the Covercrete) [16,17]. The objective of the committee was the selection of suitable NDT methods for the evaluation of the thickness and quality of the concrete cover, in view of the need for durability of concrete structures.

Comparative tests of different NDT methods to evaluate the "penetrability" of the concrete cover layer were carried out using various test methods and property evaluation philosophies. In the comparative tests, concrete panels made with different concretes (w/b ratio, binder type, curing, etc. were varied) were prepared at the EMPA laboratory in Zurich, Switzerland. Specialists of several institutions worldwide applied different in-situ NDT to measure the penetrability of the panels. Test methods used in this project are described in detail and fully referenced in the State-of-the-Art Report of RILEM TC 189-NEC [17].

Material properties tested comprised gas permeability, water sorptivity and permeability, electrical resistivity, and migration. Later, cores were drilled from the panels and sent to several laboratories, in order to perform tests under controlled laboratory conditions, the so-called reference tests, comprising tests for chloride resistance, oxygen permeability, and water absorption. All reference test methods applied in the project follow a similar test philosophy in that they mimic transport mechanisms in concrete samples preconditioned under controlled laboratory conditions.

The object of these comparative tests was to determine whether the NDT methods designed to measure on site the penetrability of the concrete cover are capable to detect differences in the w/c ratio and curing conditions of concretes. The most relevant conclusion from the work of RILEM TC 189-NEC was that today there are several suitable devices on the market, with which site measurements (non-destructively or applied on drilled cores) of the penetrability and thickness of the “covercrete” can be performed with sufficient accuracy. This is important as it indicates that reliable performance-based test methods for durability specifications are available. What is still needed is a generally accepted method for the specification of durability using the performance-based testing approach, including guidelines for the application and interpretation of such test methods.

The aim of the work of a proposed new RILEM TC, as discussed in the following section, is to develop guidelines on how to apply the above mentioned methods in practice for the performance-based specification of durability and for checking the compliance of the final product (the finished structure) with the specification.

4. PROPOSAL FOR FUTURE WORK AIMING AT DEVELOPING GUIDELINES FOR DURABILITY SPECIFICATION AND TESTING

A new RILEM Technical Committee “Performance-based Specification and Control of Durability” was proposed at the beginning of 2008. The subject matters of the TC are:
The work of the TC will also include Round Robin site testing and evaluation of real structures in different environments around the world. Using various test methods and their respective interpretation guidelines, different approaches can be assessed in view of their reliability and suitability for performance-based specification of durability.

The result of the TC’s work is expected to provide useful guidance on suitable “durability indicators” and their application in performance-based specifications for durability. An important complementary result will be issuing recommendations on sampling criteria, application of site test methods to evaluate the penetrability (NDT and cores) and thickness of the concrete cover, interpretation of results and principles of compliance control based on site tests. The recommendations will serve as a basis for harmonization and standardization of the selected approaches and methods.

5. CONCLUDING REMARKS

Many existing concrete structures show signs of deterioration, linked to the mechanisms of steel reinforcement corrosion. Often this is due to a lack of understanding of what is required to ensure durability as well as inadequate means of enforcing or testing compliance with specifications during construction. The specification of limiting material properties linked to potential concrete durability is a step in the right direction. Test methods have been developed which can successfully be employed in characterising concrete in terms of its potential durability and it can be expected that these methods will be increasingly applied in construction practice worldwide.

The work proposed to be carried out by a new RILEM Technical Committee “Performance-based Specification and Control of Durability” is aiming at developing guidelines for successful implementation of performance-based durability design and specification approaches. Such performance-based approaches can be expected to improve concrete durability in general and provide practical means to control the quality of concrete construction.
REFERENCES