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Computer-aided modeling of concrete service life

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ABSTRACT

A significant step forward for a thorough durability design process of reinforced concrete structures is the development of software packages, based on predictive models, for the estimation of concrete strength and service life. Such an attempt, in full compliance with the European Standards for cement and concrete, is presented in this study. Upon defining the concrete mix design, the software calculates the main chemical and volumetric characteristics, as well as the compressive strength, of concrete. By taking into account the environmental conditions where the structure will be exposed, concrete service life is predicted, using fundamental mathematical models (based on reaction engineering principles) that simulate the reinforced concrete deterioration mechanisms leading to corrosion of the embedded reinforcement (caused by either carbonation or chloride ingress). A validation process of the yielded results is also presented, and the effectiveness of the simulation tool in designing for durability is illustrated. The goal of this study is to promote wider acceptance in achieving feasible and durable solutions to structural concrete design problems.

1. Introduction

Given the increased number of premature structural deterioration cases observed on reinforced concrete (RC) structures, a comprehensive design process becomes imperative. Bearing in mind that such deterioration can be caused by mechanical and/or environmental actions, an in-depth understanding and modeling of the physicochemical processes that lead to concrete deterioration (under harmful environmental agents) is the first step for a valid service life estimation. On this note, certain research attempts [1–3] have been proved successful in identifying the service life of a reinforced concrete element under chloride exposure, at a probabilistic manner and also in assessing the carbonation depth in time [4].

What is missing however, is a comprehensive set of tools that will aid the designer in identifying the influence of both the most common harmful environmental agents (carbonation exposure and chloride ingress), by taking under consideration the environmental and mix design particularities of a reinforced concrete structure, in order to take all the appropriate measures (in advance) to mitigate their effect, in safeguarding a prolonged service-life of any type of structure.

On the European Standard for concrete [5] durability is approached by the definition of limiting parameters on cement and concrete composition (*W/C* ratio, cement content, etc.), as well as by the development of performance-related methods (*PRMs*). Such a method (*PRM*) is necessary when a service life significantly higher of 50 years is required, or when the environmental actions are particularly aggressive [5]. A *PRM* considers each relevant deterioration mechanism, in addition to the service life of the structure, and the criteria which define the end of this service life, in a quantitative way. It can based on data derived from established performance test methods for each relevant mechanism, or on the use of proven predictive models. Considering that in reinforced concrete the most serious deterioration mechanisms are those leading to reinforcement corrosion, it is therefore necessary, if a long service life is required, the modeling attempts to focus on these types of mechanisms/chemical attack processes. Bearing all of the above in mind, a significant step forward could be the development of appropriate software for the estimation of concrete service life, using reliable mathematical proven models, based on performance-related methods.

In this study, a deterministic simulation tool in full compliance with the European Standards for cement and concrete [5,6], based on proven predictive models developed by Papadakis et al. [7–10], for estimation of concrete service life and strength is briefly presented. Emphasis is given on the concept of service life estimation, on tool validation and utilization schemes. As an illustrative

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example, the effects of cement type and of several supplementary cementing materials on reinforced concrete durability are studied using the simulation tool.

2. Concrete service life estimation tool

The structure and the main outputs of the concrete service life estimation tool are illustrated in Fig. 1. Upon selection of the cement type (based on the full range of cement types defined in the European Standard for cement [6]) and standard strength class, as well as, selection of quantity and type of additives (types I and II), admixtures and aggregates, the concrete mix design is defined and the main chemical and volumetric characteristics of concrete (chemical composition of hydrated cementitious materials, porosity and related characteristics) are calculated. The concrete compressive strength is accurately estimated, introducing a new (recently published) approach [11], based on the cement strength class and on the efficiency factor of SCM [12–16], using a modified version of Feret's formula. By taking into account the environmental conditions where the structure will be exposed (according to the exposure classes defined in EN 206 [5]) the concrete service life is reliably predicted using fundamental mathematical models that simulate the basic deterioration mechanisms of reinforced concrete, such as carbonation and chloride penetration. Principles of chemical and material engineering have been applied to simulate the physicochemical processes [8,9]. In addition, cost and environmental aspects on concrete composition are analyzed. Finally an optimization procedure is taking place, where (if necessary) the mix design is adjusted in order to meet concrete strength and service life requirements.

Furthermore, the software package [7] offers the possibility of investigating the efficiency of various protection measures as water proof sealants, cement–lime mortar coating and inhibitors.

2.1. Service life estimation

As it was previously mentioned, principles of chemical and material engineering have been applied to simulate the physicochemical processes leading to concrete deterioration for carbonation and chloride exposure.

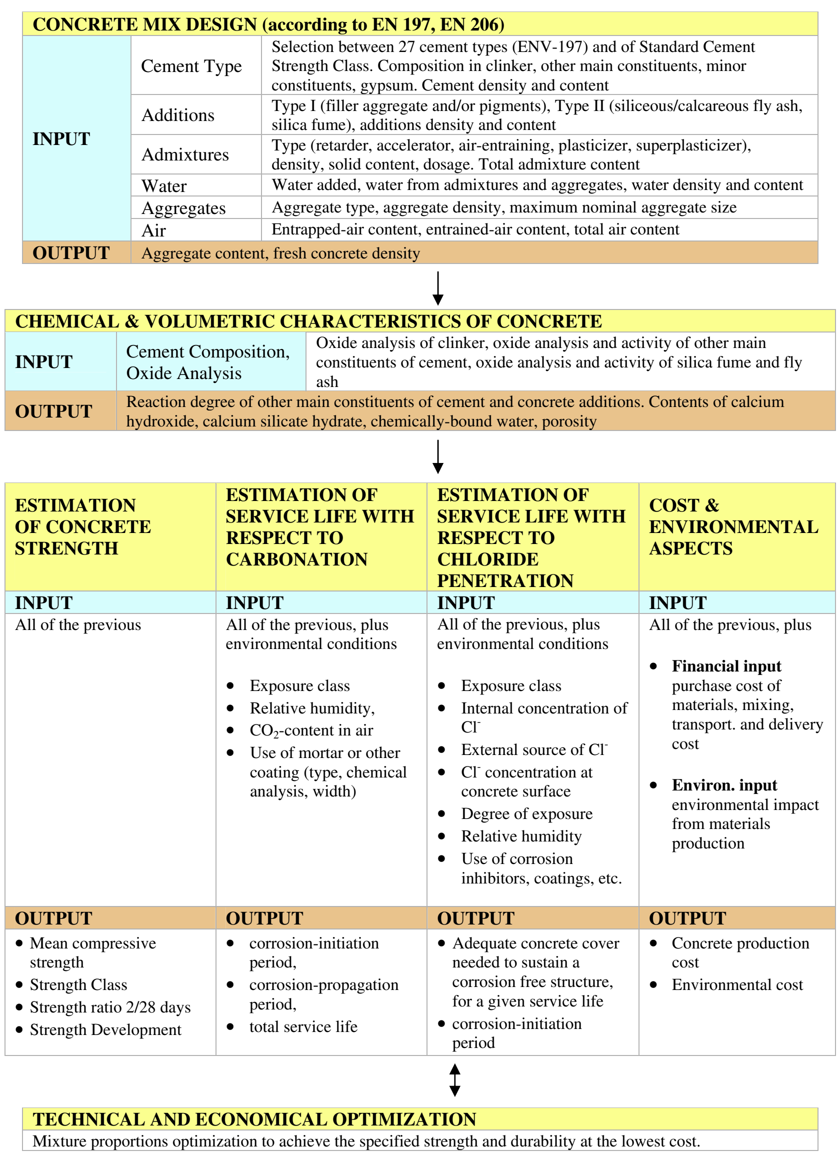

Fig. 1. Logic tree of software for estimation of concrete service life, strength, economical and environmental cost.