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Durability demands related to carbonation induced corrosion for Finnish concrete buildings in changing climate

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ABSTRACT

The study is based on durability properties of concrete collected in condition assessments and climate change prediction. According to the prediction facades will face more driving rain in the future because of increasing precipitation and windiness. Outdoor circumstances in southern Finland will ease remarkably already 2030. Initiation by carbonation dominates service life of facades because active corrosion phase is only 5–8 years for surfaces exposed to rain. However, sheltered location will remarkably lengthen active corrosion. Properties that influence initiation time are highly important in ensuring eligible service life of the structure. Present requirements are enough also in the future climate but the required cover must always be achieved.

1. Introduction

During their service life new buildings are going to face more rapidly changing climate than before. The structures in the future have to be durable enough to cut unnecessarily frequent repairs that are not part of their maintenance plan. This does not only promote sustainable development but is also cost effective property management. Even today there are known cases where durability properties have not been met which indicates that the importance of durability design in construction and repair projects has not yet been fully recognized.

Climate change itself has been studied worldwide for a long time. In this context, climate change is referred to as a global-scale warming caused by an increase in greenhouse gases, especially carbon dioxide (CO_2). Climate change will affect the geographical and seasonal distribution of precipitation, wind conditions, cloudiness, air humidity and solar radiation. Modelling of future climate is based on alternative scenarios of greenhouse gas and aerosol particle emissions. In the scenarios, different assumptions are made about the future development of population growth, economic development, energy production modes, etc. The impact of climate change on the performance of structures is becoming an important research issue from an engineering point of view.

The future of European construction industry (under Horizon 2020) will involve the adaptation of current and future infrastructure towards climate-resilience (document SWD 137 [1]). Projected impacts of climate change and associated threats concerning the construction sector are as follows: (1) extreme precipitation, e.g. leading to water intrusion, damage to foundations and basements; (2) extreme summer heat events [2], e.g. leading to material fatigue and accelerated aging, high energy use for cooling; (3) exposure of structures to heavy snowfall; (4) rising sea and river levels that increase the risk of flooding, soil subsidence risks are likely to increase.

The Finnish Meteorological Institute (FMI) has examined in the ACCLIM project the different climate models, built models for Finnish climate conditions and adaptation to climate change. In all gas emission scenarios, based on three IPCC (2007) [3] scenarios for the evolution of greenhouse gas and aerosol particle emissions, the average temperature and the change of precipitation rises equally fast until 2040. Differences among the scenarios start to emerge only after the middle of the century [4]. The FMI has also made new calculations based on IPCC recently published new scenarios. In new scenarios differences in the average temperature and change of precipitation starts earlier but the values of the most severe scenario are not going to differ significantly from the values published in ACCLIM project which are used in this study.

Nowadays the estimated life cycle in building design is typically 50–100 years, and efforts are made to lengthen the service life of the older building stock by renovation. Thus, there is a great need

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to study the performance of repaired structures and repair methods exposed to future climates. These studies are a major part of the FRAME project recently carried out at Tampere University of Technology (TUT). The project was based on data of the ACCLIM project [4]. However, the ACCLIM project is based only on a single future scenario of greenhouse gas emissions.

The ACCLIM and FRAME projects have shown that in the future climate conditions are likely to get worse in terms of durability of facades and other structures. It has been shown in the case of precast concrete buildings that presently deterioration of facades and balconies is faster in the coastal areas and southern Finland than inland and eastern and northern Finland [5]. According to the data of the ACCLIM project, precipitation during the winter season is also going to increase while the form of precipitation is going to be increasingly rain and sleet. At the same time, the conditions for drying are going to get worse. Thus, the degradation rate of structures will accelerate in most of Finland if maintenance and protection actions are neglected [6].

Research objective was to study whether the durability properties regulated by Finnish building codes are enough for the changing climate conditions. In this work a database of concrete material properties and observed degradation was combined with climate data projections from FMI.

2. Background

2.1. Corrosion of reinforcement due to carbonation

Because of its nature, corrosion of concrete reinforcement is in general depicted by a model with two distinct phases as in Fig. 1 [7].

2.1.1. Initiation phase and its modelling

Concrete reinforcement is protected from corrosion by high alkalinity of concrete pore water. This alkalinity is over time neutralized by carbon dioxide in the surrounding air or chlorides penetrating the concrete cover leaving the reinforcement susceptible to corrosion. Concerning concrete facades in a non-marine environment, the corrosion of reinforcement is mainly initiated by carbonation [5].

Although chloride-induced corrosion is considered to be worse than carbonation-induced corrosion, Parrott [8] and Jones et al. [9] states that 2/3 of all structural concrete is exposed to environmental conditions that favour carbonation-induced corrosion. Carbonation of concrete is a chemical reaction between alkaline hydroxides of concrete and carbon dioxide gas both dissolved in concrete pore water. The reaction product is calcium carbonate, which lowers the pH of the pore water (and concrete) gradually to a level where steel can corrode. As the alkaline hydroxide reservoir in concrete is limited, it is eventually used up leading to the neutralization of concrete.

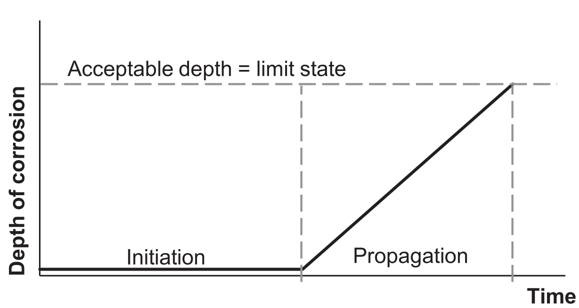

Fig. 1. The two-phase model of corrosion of reinforcement in concrete by Tuutti [7].

The evaluation of the service life of reinforced concrete structures has led to the development of several models to model carbonation evolution [7,10–17]. Carbonation has been found to involve a number of processes, from the aggressive environment of gas diffusion to the beginning of the corrosion itself, and there are several other parameters whose variability cannot be ignored. Neves et al. [18] provided a simple analytical model for the initiation period, calibrated with long-term carbonation results, which used the accelerated carbonation resistance and the environmental class as input parameters (semi-probabilistic approach). Recent work also focused on the assessment of climate change on the durability of concrete structures in specific locations. Wang et al. [19] studied the impact of climatic change on corrosion-induced damage in Australia. Talukdar et al. [20] estimated the effects of climate change on carbonation in Canadian cities. Based on those results Talukdar and Banthia [21] developed a model of carbonation in concrete infrastructure in the context of global climate change. The serviceable life, from construction through to cracking due to carbonation induced corrosion of concrete infrastructure is considered in all continents. It was concluded that global climate change will affect the progression and will result in much higher ultimate carbonation depths in the long term. Guiglia and Taliano [22] compared the carbonation measured on in-field exposed existing reinforced concrete structures with predictions made using fib-Model Code 2010. This comparison has highlighted the key role played not only by the environment, but also by the quality of the concrete through the inverse effective carbonation resistance of concrete on the evolution of the carbonation depth in time.

2.1.2. Propagation phase and its modelling

Corrosion of steel embedded in concrete is an electrochemical reaction where anode and cathode areas are formed on the steel surface as a result of differences in pH and moisture. Anode areas release positively charged hydrated ions in oxidation reaction into the pore water acting as an electrolyte. The excess electrons flow through metal from the anode to cathode where they are consumed in reduction reaction by hydrogen ions or by dissolved oxygen. The ions released in electrolyte react forming corrosion products. Corrosion, especially with shallow cover depths, leads to cracking or spalling of surrounding concrete as the reinforcing bar starts to rust forming residue greater in volume than the original bar [23]. To happen, electrochemical corrosion requires [24]:

- a reactive metal where anodic oxidation can take place,
- a reducible substance which acts as a cathodic reactant,
- electrolyte allowing the migration and movement of ions,
- an electron conduction between anodic and cathodic areas.

Therefore, amount of pore water is one of the critical preconditions for corrosion meaning that the moisture of reinforced concrete has a paramount effect on the rate of corrosion. The rise in temperature is considered to increase the solubility of chemical compounds thereby increasing also the rate of corrosion [7].

The corrosion propagation phase is now appreciated as a significant component in the service life of RC structures and a good understanding of the propagation process is paramount. Various models have been developed to simulate and/or predict the propagation phase. Empirical models are sub-divided into three types i.e.: (i) Expert Delphic oracle models, (ii) fuzzy logic models, (iii) models based on electrical resistivity and/or oxygen diffusion resistance of concrete. Three different approaches can be used to develop numerical models viz: (i) finite element method (FEM), (ii) Boundary element method (BEM) and (iii) resistor networks and transmission line method. Analytical models apply usually thick-walled cylinder approach. Division into cracked inner