

Book review

Corrosion of reinforcement in concrete—corrosion mechanisms and corrosion protection

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This publication (EFC31) is one of a series that deals with aspects of corrosion that, to date, total 31 under the auspices of the European Federation of Corrosion Publications. The papers presented were given at Euro-corr 99, held in Aachen, Germany in a session called 'Corrosion of Steel in Concrete'.

The book contains 13 short papers that are split into two groups: Part 1 deals with corrosion mechanisms and measurements; Part 2 deals with corrosion protection of reinforced concrete. The papers are concise, pithy and very focused. They are not for the technical generalist and assume the reader has some familiarity with corrosion phenomena. The publication should be read in conjunction with EFCs 18, 24 and 25.

All too often bad news about reinforced concrete is presented, leaving the impression that the material is inadequate. This book acknowledges that the majority of structures perform satisfactorily with useful lives exceeding 80 years. What is of concern is premature failure.

Part 1 of the book contains five papers: two Swiss and one each from Holland, Norway and the Czech Republic. These papers address fundamentals such as balancing the anodic and cathodic reactions. There has previously been a preoccupation with anodic reactions. One becomes aware early in this book of the merits of stainless steel reinforcement, compared to carbon-based steel, although one has to be cautious if the stainless steel has been cold-formed or welded.

At the cathode, reduction of oxygen occurs generating alkali and so the availability of oxygen and the ease with which it can diffuse to the cathode is important. The level of water saturation affects the diffusion rates of oxygen that can fall below $10^{-10} \text{ m}^2 \text{ s}^{-1}$ and controls cathodic polarisation. The role of macro cell formation is also acknowledged.

Paper 3 in Part 1 addresses those critical factors that

initiate rebar corrosion, including the critical chloride concentration at pH 13.4 when corrosion is suggested to be zero in chloride levels less than 0.2 mol/l and 100% at chloride concentrations greater than 0.6 mol/l. Confirmation of the Cl^-/OH ratio at approximately 0.6 ± 0.1 is given.

The role of concrete's surface density achieved using micro-silica additions and the consequential chloride penetration using field tests, highlights the link between concrete quality and surface accumulation of chloride. As well as concrete's surface condition one also has to take regard of the steel surface condition, for example pre-rusted, machined or scaled. In practical situations all these conditions can be met.

Part 2 consists of eight papers, two from Holland and one each from Denmark, Germany, Poland, Italy, Switzerland and the UK and is more pragmatic but still linking application with understanding. Bearing in mind that one quoted statistic in this book is that in the UK alone some 50 million ecus per year are spent on highway-related repairs, it is surprising to find that only one paper comes from the UK.

The first of the eight papers (number 6) describes a computer-based system dealing with planning and managing repair work with the emphasis on durability. This is an informative chapter but the use of terms such as hypertext, hot words, guided pathways and work-sheets does not help understanding, although you are left with a warm feeling!

Paper 7 is something of a disclosure and myth-remover regarding organic corrosion inhibitors and their limitations. Hydroxyalkylamine and benzoic acid derivatives are highlighted. High concentrations (10% in solution) are needed to stop pit corrosion initiation, although the rate of corrosion is reduced even at low concentrations (1% in solution). Adsorption onto the steel is crucial. Transposing solution experiments to

mortar specimens yielded reduced effects. Similar inhibitor to chloride ion ratios were found for nitrite and monofluorophosphates to prevent pitting corrosion.

Chemical alterations extend to silicone-based protectants for concrete with life spans of approximately five years, resisting de-icing salt penetration. There is some merit in using these materials on new constructions but of questionable purpose if corrosion is already taking place.

Four papers concentrate on electrochemical treatments of one type or another from straightforward impressed current cathodic protection to sacrificial zinc-based anode applications applied to embedded steel as well as on the concrete surface and a combination of both with embedded variants. This technology offers usable solutions to the problems of distressed structures and is clearly a field inviting innovation.

Examples are given of cathodic protection in domestic dwellings extending life spans from 5–10 years to 25, as well as sacrificial anodes to protect steel adjacent to patch repairs in chloride-contaminated concrete. Also included are layered zinc anodes as well as thermally sprayed zinc anodes coupled with coatings to protect the exposed zinc itself from corrosion. Let no one doubt the need for having available, understood and proven preventative and remedial technology in this

field. According to the US Federal Highways Agency, some 39% of US bridges are damaged (226 000) and 23% (134 000) are considered to be structurally damaged. Repairs for structural reinstatement, itself an emerging technology, may need to be integrated with these electrochemical techniques.

The final chapter reverts to the use of stainless steel and in particular austenitic AISI 316 as reinforcement alone and in conjunction with carbon-based steel. Notwithstanding the prospect of galvanic coupling between the two steels, selective replacement in 'at risk' areas of construction can apparently be very cost-effective, despite a five to eightfold material cost difference for the stainless as opposed to non-coated carbon steel. Several practical repair examples in marine situations are given.

The book contains 14 tables, 77 figures and 114 references and a short index. It is a compact volume that is a tangible bridge between theory and practice. In recommending No. 31 of the EFC series I would judge other volumes in the same series worthy of close inspection for those actively involved in the development of anti-corrosion techniques as well as their practical applications.

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