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PROTECTION AND REPAIR OF REINFORCED CONCRETE STRUCTURES BY MEANS OF MCI-INHIBITORS AND CORROSION PROTECTIVE MATERIALS

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Abstract: *In this paper the protection of reinforcing steel in new and existing reinforced concrete structures by using migration corrosion inhibitors (MCI) and corrosion protective materials (CM) which contain MCI is discussed. The composition and criteria of quality for products and systems for protection and repair of new and existing reinforced concrete structures is discussed too.*
It is also described the procedure of the restoration with the MCI-inhibitors and materials contended this inhibitors of the reinforced concrete structures of the module no. 3 on the wharf mo. 5 in the harbour Ploče.

1. INTRODUCTION

According to statistical indicators, damages of the reinforced concrete structures caused by the corrosion of the reinforcing steel make more than 80% of all damages of the reinforced concrete structures.

Corrosion protection of the reinforcing steel and the protection of the new and the restoration of the old reinforced concrete structures by means of MCI-corrosion inhibitors and anticorrosion materials, as well as with the systems, which contain these inhibitors, represents important contribution and big step forward to the prolongation of the durability and the lifetime of the reinforced concrete structures, and herewith to the major reduction of the maintenance costs, as well as to the effectiveness of the building use. MCI-corrosion inhibitors and anticorrosion materials and the systems, i.e. those, which contain these MCI-inhibitors for the protection of the reinforcing steel and the protection of the new and the restoration of the old reinforced concrete structures, have been used successfully around the world for over 25 years.

Product of the iron corrosion /Fe is iron oxide /Fe_xO_y:

$2\ Fe + 1\ ½\ O_2 + H_2O + heat \rightarrow 2\ FeOH$

1 vol ca. 2,5 vol

-"Pure" iron oxide has ca 2,5 times bigger volume than metallic iron.

-Reinforcing steel is not pure iron, but its alloy: steel.

-Products of corrosion are iron oxide mixture, depending on the compound and concentration of the reactants, and on the thermodynamic conditions at which the electrochemical corrosion reaction unfolds, and the volume of the developed corrosion products is ca 3-12 times bigger than the initial volume of the reinforcing steel/iron.

-Corrosion occurrence on the surface of the reinforcing steel causes not only decrease of adhesion/adherence between the reinforcing steel and the concrete, as well as the reduction of the reinforcing steel section, but also – due to the big increase of the volume of the corrosion products in relation to the initial reinforcing steel volume – huge pressures, which cause appearance of the fissures, setting apart, cracking and scaling of the concrete protection layer above the reinforcing steel.

2. MIGRATORY CORROSION INHIBITORS

Migrating corrosion inhibitors are chemical compounds on the amine basis (e.g. aminocarbocsylates, amino alcohols, and o.), which through the process of chemical adsorption, so called chemisorptions, »bind»/adsorb on the surface of the reinforcing steel/iron (and other metals), making on the surface an firm and resistant micro layer thick ca 20 μm, resistant to many aggressive substances from the environment, primarily to the impact of the chloride, in the nature omnipresent, and simultaneously very aggressive against the iron oxides, which it chemically destroys.

MCI-corrosion inhibitors protect the reinforcing steel against the corrosion in both oxidation ranges: cathode and anode range, in distinction from some other types of corrosion inhibitors, such as e.g. nitrites – therefore are MCI-corrosion inhibitors also designate as mixed corrosion inhibitors.

MCI-corrosion inhibitors on the basis of amine compounds belong to the group of so called cathode, respectively cathode-anode inhibitors, which adsorb (through chemisorptions) on the surface of the reinforcing steel, preventing diffusion of the corrosion reactants (O_2,

H_2O) to the do reinforcing steel, and in this way they protect it against the oxidation processes, in distinction from anode inhibitors on the nitrites and/or chromates basis, which protect the reinforcing steel from the corrosion through the anode passivisation, so that they themselves participate in the anode process, i.e. oxidize instead of main metal.
Only the mechanically deteriorated concrete layer is removed, until the internal adhesion and the adhesion to the reinforcing steel of $\geq 1{,}5$ N/mm^2 is reached, and upon that:
1. Cleaned and made rough substratum is impregnated by means of MCI-inhibitor,
2. Concrete surface is reprofiled and open reinforcing steel closed by means of repair mortar, which contains MCI-inhibitor and
3. The concrete surface is finally worked out with the protective-decorative coat or hydrophobic impregnation, both containing MCI-inhibitor aiming at the protection of the reinforced concrete structure against moistening, impact of the atmospheric agents, freezing, salts and other aggressive impacts in the environment.
It is important to stress that the protection of the reinforcing steel against the corrosion and the protection of the new, respectively old reinforced concrete structures needs to be performed applying complete protection system, as stated and not only partial, because only full protection system protects the reinforcing steel enduringly and efficiently against the corrosion and the reinforced concrete structure against the deterioration /damage.

3. QUALITY CRITERIA FOR THE CORROSIVE REPAIR-PROTECTIVE MATERIALS AND SYSTEMS

3.1. Quality criteria of the cleaned concrete

Quality criteria of the cleaned concrete substratum and of the reinforcing steel of the reinforced concrete structures for the application of the Ac-repair-protective systems containing MCI-inhibitors:
1-Tensile strength of concrete substratum and adhesiveness of the concrete and reinforcing steel: $\geq 1{,}5$ N/mm^2
2-Surface roughness – depending on the repair mortar layer thickness: ca 5mm for layers with thickness ca 10-50 mm and ca 1mm for layers with thickness 2-10 mm
3-pH: alkaline range, >9
4-Chlorides concentration: without limit (some authors state max 1%)
5-Openness of the concrete surface structure: >50% visible aggregate grains, degree of coverage of the grains with the cement matrix ca 2/3 grain volume 6-Cleaness grade of the cleaned reinforcing steel: min SA 2 resp. St3 (according to international standards ISO 8501-1, SIS 05 59 00 1967, DIN 55 928-Teil 4, ASTM D 2200-67, SSPC VIS) depending on the cleaning method: sandblasting, shot blasting, hydro dynamically, manually.

3.2. Quality criteria of corrosion protective

Quality criteria corrosive repair-protective system/layer materials above the reinforcing steel: concrete, resp. repair mortar, protective-decorative coat, resp. hydrophobic impregnations, all containing MCI-inhibitors:

1-Fluids impermeability: Gases permeability coefficient ≤ $1x10^{-16}m^2$ (EN 993-4)
2-Chlorides diffusion: < $1x10^{-12}$ m^2/s (GF)
3-Capillary water absorption coefficient: $<10^{-1}kg/m^2h^{1/2}$ (HRN.U.M8.300)
4-Alkalinity: pH > 9,5
5-Anticorrosive reinforcing steel protection expressed in corrosion current intensity/density:
- Accord. to ASTM STP 1065: < 0,1 μA/cm^2

4. PROCEDURE OF THE RESTORATION OF THE REINFORCED CONCRETE STRUCTURE OF THE MODULE NO.3 ON THE WHARF NO.5 IN THE PORT PLOČE CARRIED OUT DURING THE YEAR 2005

The works were carried out by the company ŠKILJO-GRADNJA, Zagvozd, according to the restoration project elaborated by the company GEOKON, Zagreb. The quality of the used materials and of performed works has tested and controlled IGH-Regional centre, Split.

Figure 1: The module No. 3 in port Ploče

4.1 Preparatory works

Cleaning of the concrete surface and reinforcing steel through hydrodynamic removal of the deteriorated material with the high pressure water jet (>2000 bar) with a view to prepare the substratum for the application of the material of the repair-protective system: from the reinforcing steel separated and deteriorated protective concrete layer was removed all to the sound, clean and firm substratum (quality criterion: tensile strength of the concrete substratum and adhesiveness between the concrete and reinforcing steel: ≥ 1,5

N/mm^2). Corroded reinforcing steel was cleaned with the hydrodynamic water jet to the cleanness grade min SA2 resp. manually to St3. High pressure pump was placed on the floating platforms from which the applying of the repair mortar and the final superficial treatment with the protective-decorative coat, resp. with the hydrophobic impregnation was performed. Transport of the material and the communication of people were performed through the openings in the reinforced concrete slab.
Corrosion protection of the reinforcing steel was performed with the polymer cement coating, containing MCI-inhibitor. Application with the brush in 1-2 layers, consumption cca 0,2 kg/m ^{1}2 mm, for the12 mm diameter reinforcing steel.

4.2 Impregnation

Impregnation of the entire concrete surface was with the water solution (1:4) of the corrosion inhibitor MCI – in powder**.** Application was with the brush or roller in 2 layer of the total yield cca 25 m^2/kg.

Figure 2.: Impregnation concrete surface

4.3 Reprofilation

Reprofilation of the concrete surface and the covering of the exposed reinforcing steel was performed with the repair mortar containing MCI-inhibitor, with the manual application in 1-3 layers depending on the total thickness of the mortar layer (on some areas mortar thickness even to 8 cm). Freshly applied repair mortar needed “curing”/protection against to fast drying and loss of technological moisture. On the concrete surfaces of the faces of the wharf, exposed to the insolation and to the air circulation, freshly applied repair mortar was protected from the to fast drying by means of the curing on the basis soya oil containing MCI inhibitor, applied with the brush or roller in one layer, yield ca 5 m^2/l.

Figure 3.: Reprofilation concrete surface

4.4. Protection of the entire surface

Protection of the entire surface, i.e. concrete and reprofiled with the repair mortar, from the impact of the moisture and atmospheric agents was performed with the protective-decorative coat, or hydrophobic impregnation:
- *Wharf face* was treated with the protective-decorative coat (colour light grey) on the basis of 1-k acrylate binder containing MCI-inhibitor, applied with the brush or roller in two layers of the total yield ca 8 m^2/l and,
- *Concrete surfaces on the soffit and in the interior of the structure* were protected with treatment with the hydrophobic impregnation on the basis of sylane-syloxane in the water medium containing MCI-inhibitor, application with the brush or roller in 1-2 layers, treated surface does not change appearance or colour, yield, ca 3,5m^2/l.

Figure 4.: MCI coating on the concrete surface

4.5 Report by the IGH-PC Split

Report by the IGH-PC Split on the quality control of the built in material and on the quality of the realised works is positive, so it is stated in:
- it.2.1. Preliminary testing of the quality of the chosen material: on the basis of the obtained test results, it was concluded that the restoration corrosive repair mortar conforms to the criteria stated in the Working project of the design company GEOKON
- it.2.2. Preliminary testing of the quality of the readiness of the substratum: tensile strength of the concrete substratum „pull off" comes to > 1,5 N/mm^2, through which fact it conforms to the required criterion, as well as chlorides concentration, which comes to <0,4%
- it.2.3. Control testing of the quality of the built in material: on the basis of the obtained continuous test results in relation to the repair mortar quality, it was concluded that the repair mortar built in at the wharf no.5, module no.3, in the port Ploče conforms to the conditions and criteria stated in the Working project
- it.2.4. Control testing of the quality of the realised restoration system: on the basis of the daily obtained continuous test results in relation to the repair mortar quality, it was concluded that the repair mortar built in the every porthole of the module no.3, in the port Ploče conforms to the conditions and criteria stated in the Working project
- it.3. Final evaluation of the continuous control quality: it was confirmed that the quality of the materials and works was proved through prescribed and documented testing and that it is in accordance with the conditions and criteria given in the Working design "Restoration of the soffit and the face of the reinforced concrete structure of the wharf no.5" elaborated by the company GEOKON, Zagreb.

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