ANTICORROSION SYSTEMS AND DUCTILE MATERIALS FOR REINFORCED CONCRETE STRUCTURES

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Abstract: The main problem concerning the premature failure and the degradation of reinforced concrete (RC) structures is the corrosion of the reinforcement due to chloride contamination of the covercrete. In this contribution recently developed systems for prevention and repair of damaged concrete structures are presented. These systems contain two different technologies: MuCIS which stands for Multiple Corrosion Inhibiting Synergies and HFE-tec which stands for High Fracture Energy Technologies. While corrosion inhibitors which are applied on the surface of corroding reinforced concrete elements have shown little effect the MuCIS system takes advantage of synergies and in this way corrosion can be prevented effectively. Experimental results obtained according to an ASTM test will be presented and they clearly show the effectiveness of the MuCIS system. The efficiency has been verified on more than 8 years period through measurements obtained by the monitoring of a viaduct. HFE-tec involves ductile cement based materials such as SHCC – Strain Hardening Cementitious Composites - and ultra high performance concretes (UHPC). In many seismic areas worldwide there is a strong need of durable and at the same time highly safe reinforced concrete construction and repairs. These materials are suitable for the construction or retrofitting of seismic resistant structures or elements. The

combined use of these technologies Multiple Corrosion Inhibiting Synergies and High Fracture Energy Technologies leads the realisation of highly durable structures and repairs.

1. INTRODUCTION

There are multiple reasons why reinforced concrete structures are getting deteriorated. Climatic conditions, structural design and the choice of specific materials are among major influences. Chlorides from deicing salts and sea water are one of the main causes for corrosion damage in concrete bridges and other road structures. The corrosion of concrete constructions is a complex process that is largely influenced by the interaction of the environment with the reinforced concrete. At bridge structures with direct weathering and splash water, corrosion rates up to approximately 0.4 to 0.6 mm/year are to be expected, while structures with indirect weathering clearly corrode more slowly (< 0.01 mm/year) [1].

It is well known, that the passivation and the complex electro-chemical processes on the surface of steel reinforcement play a fundamental role. If serious and early damage is to be avoided or if damaged structural elements have to be repaired, appropriate techniques and suitable materials have to be used.

The design of a new infrastructure or the repair of an existing structure mainly focusses on static and dynamic loads. In the last years powerful numerical tools have been developed for the calculation of the mechanical behaviour of such RC structures. Other aspects related to the durability like the physico-mechanical (differential shrinkage), the influence of time and the stochastic nature of properties of building materials and their behaviour are underestimated. Thermal and hygral gradients as well as other restrained deformations induce a complex state of eigenstresses in the concrete cover. The induced tensile stresses exceed the relatively low tensile strength of the concrete particularly at early age, thus leading to crack formation at the surface zone in the covercrete. The presence of the cracks, the stochastic distribution of the position of the external reinforcement bars and of the concrete properties (strongly varying within the concrete cover) facilitate the penetration of harmful substances through the covercrete towards reinforcement. After 10-20 years the presence of these aggressive substances induce the corrosion of the reinforcement bars.

When it became quite obvious that damage due to carbonation of the concrete cover and due to the chlorides contamination was unacceptably frequent, the thickness of the cover as required by standards has been slightly increased. It was not generally recognized, however, that this modification only shifts the initiation time before corrosion of the steel reinforcement by a few years, which does not really solve the problem. The increased distance between surface and reinforcement bars reduces the redistribution effect of the cracks, so that they become wider and deeper. This measure is therefore uneffective against a premature deterioration of RC structure.

In order to increase the service life of RC structures, Wittmann [2] proposes to design the construction with respect to the static and the durability requirements in a separated way. It is pointed out that concrete has to fulfil two totally different assignments in a structural element. The mechanical properties have to ensure stability and rigidity of the structure. At the same time, the concrete cover has to prevent corrosion of the steel reinforcement.

In this contribution is shown in which way the combined use of MuCis and HFE-tec technologies lead to the fulfillment of the durability and structural requirements in case of the repair of existing structures or used as preventive measure in new structural elements.

One of the interesting properties of these technologies is the function as chloride barrier. Some chloride profile of exposed specimens will be presented.

The role of corrosion inhibitors will be briefly outlined and it will be shown in which way corrosion inhibitors can be applied in repair systems. The mechanical behaviour of new ductile and crack resistant repair mortars to protect the reinforcement is given additionally.

2. MULTIFUNCTIONAL CONCRETE COVER

2.1 Concept

If we design reinforced concrete elements for the expected mechanical load exclusively in the first step, the concrete cover may be 30 to 40 mm. In this case, the concrete can be a good structural concrete which fulfills the static requirements completely (see Tab. 1). Then a protective layer has to be be designed with respect to a given aggressive environment in a second step. The requirements of this part of the covercrete (protective layer) are totally different as compared to those of the structural concrete. In Tab. 1 the most important properties of the structural concrete are compared to the properties of the protective layer. In this case the protective coating is not load bearing but has to be very deformable and ductile in order to remain free from cracks during the designed life span. It is unlikely that weak zones of the protective coating coincide with cracks or rock pockets of the underlying concrete. The mass of the protective coating is rather small as compared to the mass of the entire concrete element. For this reason, we can apply specific additives in order to obtain high resistance with respect to chloride penetration, for instance, in an economical way.

Comparison of the most important properties of the structural concrete and the protective layer.

structural concrete	**protective layer**
required mechanical strength	high ductility and creep
required Young’s modulus	reduced shrinkage

reduced creep and shrinkage	high frost resistance
aggregates not subjected to alkali-silica reaction	high thermal volumetric stability
	chloride barrier
	carbonation resistance
	high sulphate resistance
	reduced water absorption

Table 1: Comparison of the most important properties of the structural concrete and the protective layer

2.2 Realisation of a multifunctional covercrete

For practical realizations, there are at least two different possibilities to achieve a multifunctional covercrete:

- Impregnation of part of the concrete cover a posterior
- Application of a cement-based coatings

Fig. 3 shows these two different variants for the effective protection of a reinforced concrete structure.

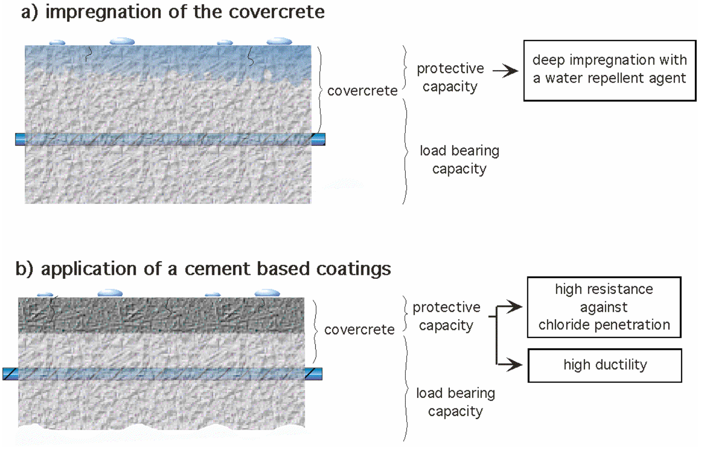

Figure 1: Possible variants for the practical realisation of a multifunctional covercrete a) impregnation of the covercrete b) application of a cement based coating

3. IMPREGNATION OF THE CONCRETE COVER

In the first case, the conventionally designed concrete cover is increased by about 10 mm. This layer can be impregnated by a water repellent agent, for instance (see Fig. 1a)). This type of surface treatment increases the resistance with respect to chloride penetration considerably. Fig. 2 shows the chloride profile of a standard concrete (w/c=0.55) and the same concrete impregnated with the multifunctional agent MuCIS mia 210/PH after a cyclic load with a chloride solution during 28 cycles (196 days).

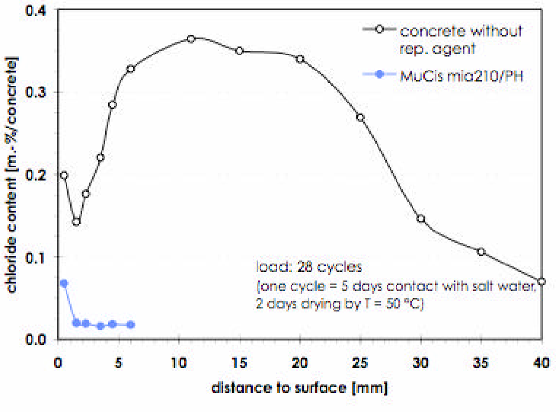

Figure 2: Chloride concentration profiles of a impregnated and the corresponding untreated concrete (w/c=0.55)

The duration of a cycle is 7d. The surface of the specimen is in contact with a 3% chlorine solution during 5 days, then the specimen is placed in a oven at T=50°C) for drying during 2 days. It is impressing how the impregnated concrete impeded the chloride migration through the covercrete. In this way the amount of chloride in the impregnated cover is reduced by 5% as compared to the concrete without surface treatment. In order to achieve these performances the penetration depth of the water repellent agent must at least be grater than 5 mm. Fig. 3 shows the water absorption profile of two different treatments as function of the distance from surface.

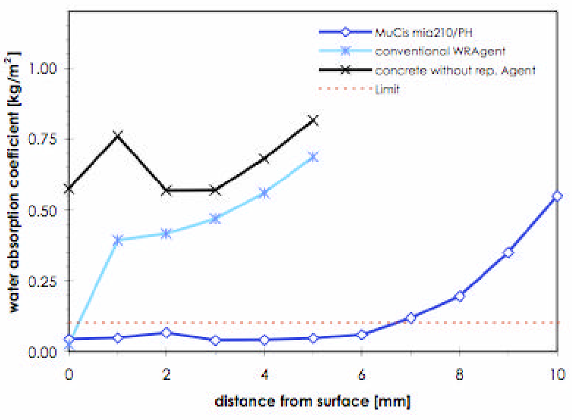

Figure 3: Water absorption profiles of three impregnated concrete and the reference (untreated concrete, w/c=0.55)

The water absorption coefficient of the untreated concrete is about 0.7kg/m2. This concrete has been impregnated with 2 different products. These products have been applied fresh on fresh in a amount of two time 150g/m^2. In the case of impregnation with a conventional water repellent agent (solvent based) a penetration depth of 0.5mm is reached. The agent MuCIS mia 210/PH penetrate at 6.7mm.

If an efficient application technology for the water repellent agent is applied [3,4], the surface treatment reduces also internal hygral stresses of drying concrete elements and hence surface shrinkage cracking is reduced [5]. As the drying process is slowed down the structural concrete will be well cured under the protective layer [5].

Due to the limited stability of hydrophobic compounds in alkaline environment, the impregnated surfaces have to be reimpregnated every 15-20 years. Particularly exposed surfaces have to be repaired probably despite the different impregnations. It can be concluded that this kind of intervention is able to improve the service life of a construction 2 or 3 times before a drastic rehabilitation.

4. CEMENT-BASED PROTECTIVE COATINGS

4.1 Application fields and required properties

The structural element can also be coated with a cement-based mortar. This is normally the case for the repair of damaged structures where the contaminated covercrete has to be substituted. Protective cement-based coatings are also applied on particularly exposed structural elements. The composition of the protective coating has to be designed in a way as to prevent access of aggressive compounds to the load bearing reinforced concrete structure and to remain free of cracks within the desired service life. If this goal is not completely met or if the environmental conditions are very extreme, the contaminated protective coating can be renewed after 40-50 years in an economical and ecological way. In this way the structural element is integrally protected and remains uncontaminated during the whole service life. If this repair measure eventually becomes necessary can be checked by appropriate monitoring systems.

4.2 High ductility and crack resistance

In order to ascertain long-term durability, however, the mechanical stability of the repair layer must be guarantied. This is by far not obvious. Surface layers shrink and are exposed to thermal gradients. Both actions provoke complex states of stress. Crack formation and delamination can be the result [6]. The ductility of cement based coatings is one of the key parameter to maintain this external layer free from cracks. This task can be achieved when a special designed mortar is modified with organic high modulus fibers. Particularly ductile fiber reinforced cement based materials (HFE-tech - SHCC) show a completely different behaviour in tension compared to plain concretes or standard fiber reinforced concretes (FRC). The tensile response is more similar to the strain harding behaviour of metal-like materials (see Fig.4) than to the quasi brittle behaviour of mortars and concretes. The strain capacity and the fracture energy of SHCC are approximately 500 times higher compared to FRC.

Fig. 4 shows the tensile strain capacity of the mortar HFE-tec – SHCC. This capability to absorb deformations without failure makes it the ideal material for any application that is exposed to deformation controlled loading such as hygrally or thermally induced shrinkage (repair), settlements, or seismic activity. Even in case the applied deformation exceeds the maximum elastic strain the tensile load bearing capacity is maintained further up to a level of at least 3% of tensile strain.

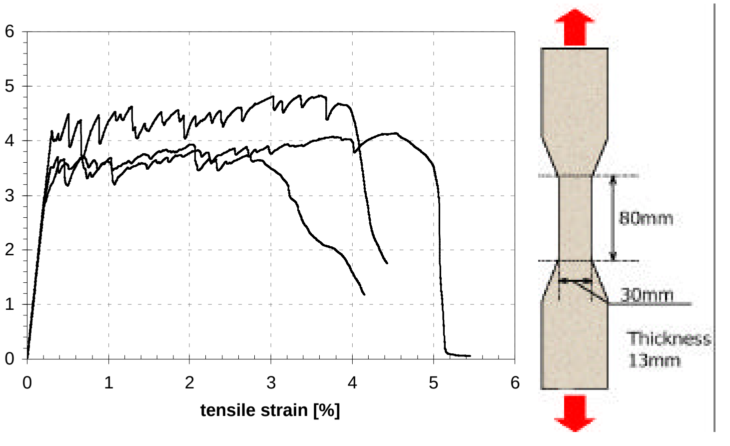

Figure 4: Tensile strain capacity of the described HFE-tec SHCC determined by means of direct tensile tests (3 specimens)

4.3 Anticorrosive and chloride barrier function

In the system MuCIS (Multiple Corrosion Inhibiting Synergies) migrating inhibitors and interface corrosion inhibitors are combined with agents to stabilise the hygral situation in concrete. In this way cathodic and anodic protection of the reinforcement can be achieved. At the same time MuCIS is an effective barrier against penetration of dissolved chlorides. This system has been tested in the laboratory and is now applied on important structures on which corrosion has been observed. In order to check the effectiveness of the MuCIS system long-term tests have been carried out. The corrosion current of steel reinforcement has been measured as function of time and under the conditions of the ATSM test G109. Some typical results are shown in Fig 5. In Fig 5 the corrosion current as measured in untreated and in similar concrete with an addition of 0.5 % chloride is shown. As can been seen the corrosion process starts in both types of concrete right away under the conditions of testing. In Fig. 5a the corrosion current of similar specimens but covered with a layer of MuCIS repair system BS 39 having a thickness of 2 cm is shown in addition. In this case the measured corrosion current indicates that after application of the MuCIS system corrosion of the steel reinforcement is effectively prevented. In Fig. 5b results of another test series are shown. In this case the chloride content of the concrete base on which the repair layer has been applied has been varied from 0.3 % to 1.0 %. It can be seen that independent of the chloride content of the substrate corrosion is prevented after the application of MuCIS system BS 39.

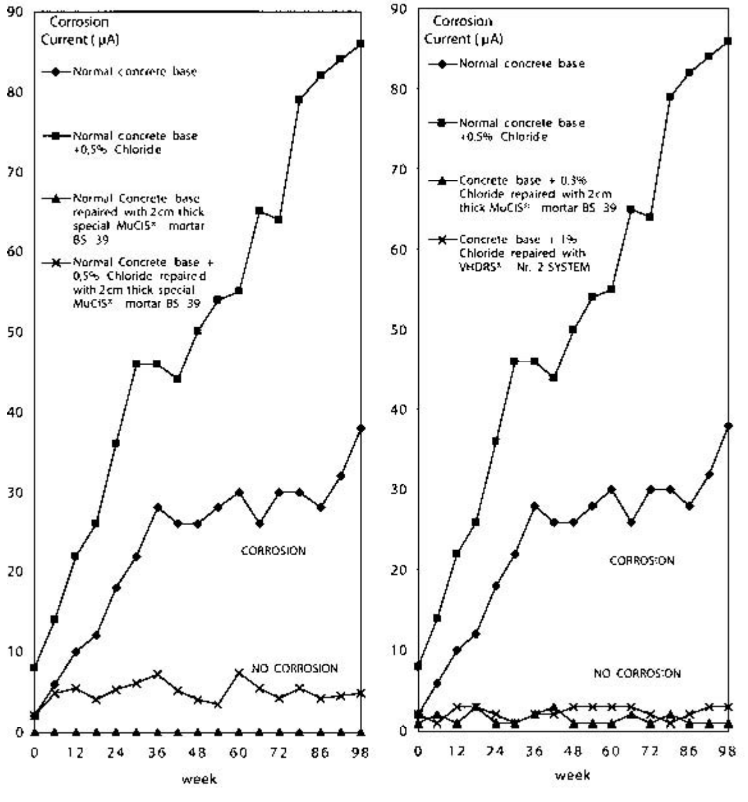

Figure 5: Corrosion current of different systems according to ASTM test G109

5. CONCLUSIONS

In many cases, the designed or expected service life of concrete structures is not reached without important repair measures. A probabilistic analysis shows clearly that conventional concrete covers will often fail to protect the steel reinforcement from corrosion. Even though the concrete cover may be increased, the durability of the structure remains clearly limited.

It is suggested that the mechanical and protective assignments of concrete cover are treated separately. In this case, cement-based coatings can be optimized with respect to ductility, resistance ion-penetration and anticorrosion function. It is shown that impregnated concrete cover with MuCIS products and very ductile mortars (HFE-tec- SHCC) exhibit significantly reduced chloride penetration and protect the reinforcement from corrosion efficiently. The combined use of these technologies Multiple Corrosion Inhibiting Synergies and High Fracture Energy Technologies leads to the realisation of highly durable structures and repairs.

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