TECHNICAL ARTICLE
Sika solutions for recurrent problem of low concrete cover in reinforced concrete structures

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FOR EXTERNAL DIFFUSION

TABLE OF CONTENTS

1 ABSTRACT

The problem of low cover to reinforcement bars in concrete can be solved by adding additional mortar or concrete to the external surface (Principle 7 method 7.1 of European Standard EN 1504-9), or by applying protective coatings (Principle 1 method 1.1 and 1.3 of European Standard EN 1504-9) or intumescent coatings. This technical paper discusses the various Sika solutions and levels of protection which can be applied to protect concrete.

2 INTRODUCTION

One recurrent problem in reinforced concrete buildings and civil engineering structures is the inadequate concrete cover to the embedded steel reinforcement.

Before defining a solution to the problem, a clear understanding of functions and requirements of the concrete cover is required.

In reinforced concrete, the concrete cover primarily has three distinct purposes:

1. Fire concern: Provision of fire protection to steel reinforcement
2. Durability: Protection of steel reinforcement against corrosion due to aggressive environments (e.g. carbonation or chloride ingress)
3. Structural: Enable force transfer from reinforcing bars to concrete without splitting (not addressed in these WIKI pages)

3 FIRE PROTECTION TO STEEL REINFORCEMENT

The Structural Engineer determines if there any areas of low concrete cover which can reduce the fire protection capability to the steel reinforcement.

If this is the case, the possible solutions are to increase the concrete cover to the specified thickness by adding mortar or concrete, or to apply an intumescent coating to provide fire protection.

3.1 INCREASING COVER WITH ADDITIONAL MORTAR OR CONCRETE

Adding an additional layer of mortar or concrete on the surface will increase the amount of cover to the reinforcement bars. This corresponds to method 7.1 (increasing cover with additional mortar) of principle 7 (Preserving or restoring passivity) of EN 1504-9.

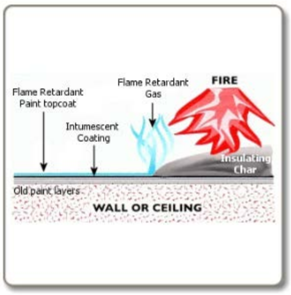
In Europe, the mortar shall comply with requirements of the EN 1504-3 Class R3 or R4 (according to the specified concrete compressive strength). The mortar should also have the same or higher level of carbonation resistance as the specified concrete when tested in accordance with European Standard EN 13295. The additional thickness of mortar should correspond to the amount of additional concrete cover required by the Engineer.

All mortar shall have Class A1 (Euro class) behaviour in fire.

A typical Sika solution for this type of application is Sika MonoTop®-412 N (Class R4, positive carbonation test and class A1 fire resistance).

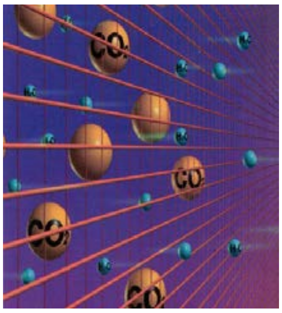
Proper curing of the additional concrete or repair mortar is essential. Excessive evaporation leads to shrinkage and cracking resulting in ineffective protective functions.

3.2 INTUMESCENT COATINGS



An intumescent material is a substance which swells under the influence of heat. It increases in volume and decreases in density. Intumescent coatings are typically used in passive fire protection. Sika provides full range of intumescent coatings (Sika® Unitherm®) for steel and concrete protection.

4 REINFORCEMENT CORROSION PROCESS



The exposure condition on a structure has an influential role on its durability. Concrete structures with low cover will most probably experience a shorter life cycle in highly corrosive conditions, such as marine environments.

The two most universal causes of reinforcement corrosion are carbonation and chloride attacks. The faster these penetrate the concrete, the sooner the passive layer around the reinforcement bars is destroyed and corrosion process initiated (for more information, refer to Sika Technical News N° 05.07 dated October 2007, available on Sika intranet or upon request).

Detailed information about concrete protective coatings and durability are also explained by Dr. Robert Engelfried[1].

4.1 CARBONATION PROTECTION

4.1.1 CARBONATION – SINGLE LEVEL OF PROTECTION

The specified level of protection against future carbonation can be restored if applying a protective coating with a CO2 diffusion resistance coefficient that conforms to the minimum defined in EN 1504-2 (SD>50 m).

Example

Using the value of non-coated concrete in report A-14’231-1E[2] (µb = 1 012) the equivalent concrete cover for a given dry film thickness of the protective coating can be calculated:

Sikagard®-675 W ElastoColor (report A-33’884-2E[3]

Calculated coefficient µ:	370’000
Dry film Thickness (dft):	180 µm
Typical Concrete Coefficient µb:	1’012
Equivalent thickness:	(µ / µb) x dft(mm)
	(370’000/1’012) x 0,180
	= **66 mm** of equivalent concrete cover

The protection system described above requires a uniform and level concrete surface free from defects such as blowholes and high spots or other irregularities. A level concrete surface will help ensure a homogeneous coating film thickness (particularly important if the coating is intended to function with crack bridging properties) and help to prevent blistering due to water penetration through areas of weakness.

A cement-based leveling mortar such as **Sika MonoTop®-723 N**, or a filled acrylic intermediate **coating Sikagard®-545 W** as surface fairing / leveling or ‘scratch’ will provide the necessary level surface prior to application of a protective coating.

4.1.2 CARBONATION – TWO LEVELS OF PROTECTION

Increasing the level of protection will increase durability and service life. A corrosion inhibitor can act as a second level of protection to increase the carbonation resistance. The corrosion inhibitor is applied before the protective coating and acts by migrating into the concrete to form an additional protective layer over the surface of the embedded steel reinforcement.

Surface applied corrosion inhibitors provide particularly good performance in preventing and reducing carbonation induced steel corrosion. This was shown by Heiyandtuduwa[4] (refer to figure 2) and Taché[5].

Additionally, as the concrete cover is lower than originally specified, it is reasonable to expect higher penetration rate and increased volume of the inhibitor reaching the steel surface.

Sika® FerroGard®-903+ application process allows the protective coating to be applied soon after the inhibitor application when the concrete has dried sufficiently (refer to the Sika Method Statement for more details).

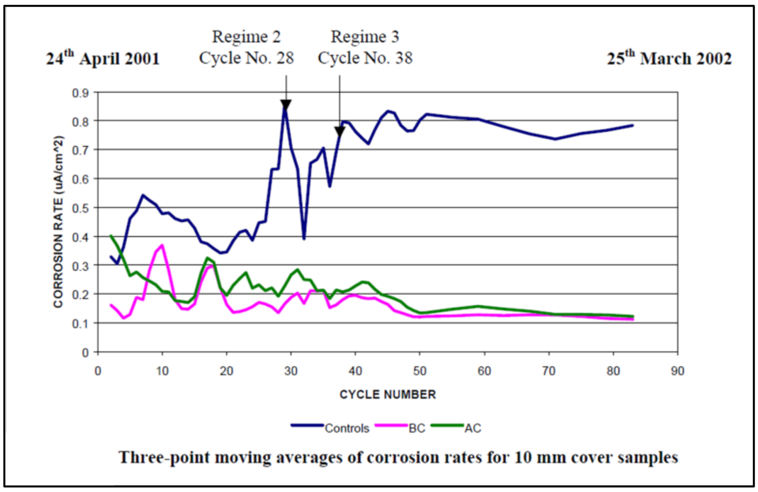


Figure 1: Carbonated concrete - inhibitor effect (applied before and after carbonation)

When protective coatings eventually deteriorate it may no longer protect the concrete adequately. Typically this may be after 10-15 years or longer depending on the exposure. When the protective coating is fully or partially destroyed carbonation can continue to travel towards the steel reinforcement and in the presence of moisture corrosion of steel can start. The advantage of applying a corrosion inhibitor as a second level of protection however is the inhibitor film formed around the reinforcing bars which continue to protect the steel.

By applying the corrosion inhibitor the Engineer would have some time to schedule the next maintenance action (e.g. re-application of 1 or 2 coat(s) of the protective coating) without risk of deterioration in the structure if the coating was damaged.

Typical exposures which contribute to the deterioration of protective coatings are reduction of film thickness by the ultra-violet rays and chalking; mechanical erosion from wind and rain including wind borne dust and sand abrasion etc.

4.1.3 CARBONATION – FAST APPLICATION METHOD

For a protective coating to be effective and durable it has to be applied on a defect-free surface as discussed in section 2.1.1. Therefore a pore-filling, fairing, levelling or scratch coat normally needs to be applied to provide this.

In some situations it may not be practical to provide a defect-free surface in this way. For example on very large civil engineering structures such as cooling towers or bridges the curing requirements, application steps, time and cost may prevent this.

An alternative strategy would be to apply firstly a compatible hydrophobic impregnation in place of the fairing coat onto the defective surface. Most of the risks associated with applying a protective coating on an inadequately pre-treated surface can then be reduced. Not only is this alternative strategy much quicker and easier to apply, this method can still result in a long durable protection system (note that the coating calculation in 2.2.1 is still valid).

The hydrophobic impregnation will compensate where there are surface defects to repel water as a second level of protection where the protective coating has not filled or bridged the pores, cracks or other imperfections. Water containing soluble aggressive elements (e.g. chlorides, sulphates etc.) will be prevented from penetrating the concrete.

Additional problems such as blistering of the coating and scaling of concrete from the effects of freeze and thaw action are also prevented by repelling the water.

This combined system is included in several different approved protection systems for the protection of concrete façade surfaces in Germany and is referenced as OS 2 as per DIN V 18026.

4.2 INDUCED CHLORIDE CORROSION

Concrete cover is the first barrier against the penetration of water soluble chlorides reaching the steel reinforcement. In marine environments or other structures subject to de-icing salt exposure this concrete cover is critical to the durability of the concrete. The greater the concrete cover the longer it takes for aggressive elements to reach the reinforcement.

4.2.1 CHLORIDE – SINGLE LEVEL OF PROTECTION

Durability can still be reinstated using a surface applied corrosion inhibitor in situations of low concrete cover where the chloride concentration in the concrete cover is still fairly low.

On new structures durability will be extended if a corrosion inhibitor is applied before soluble chlorides have had time to penetrate the concrete. This preventive action of surface applied corrosion inhibitors was clearly demonstrated by Dr. J. R. Morlidge of the UK's BRE[6] – refer to figure 2.

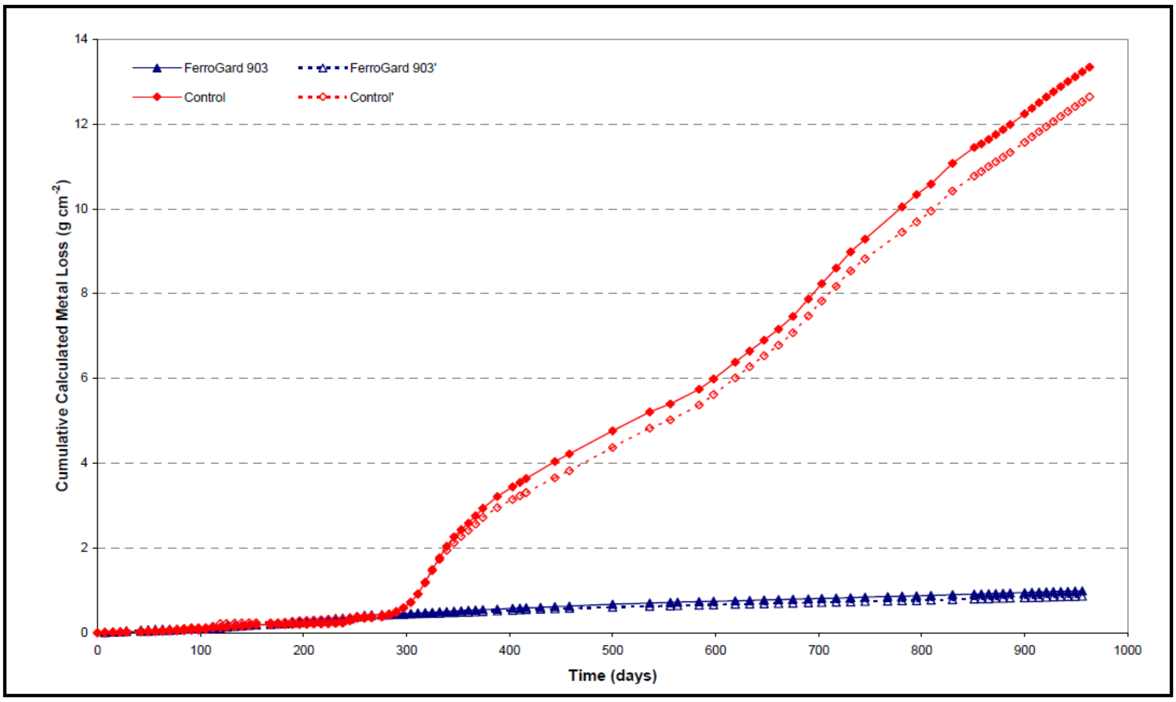


Figure 2: Cumulative quantity of steel lost by corrosion

The SAMARIS project recommended carrying out a preliminary investigation to assess if a corrosion inhibitor can be applied on a project.

As an example some preliminary questions were first considered:

Location: Is the intended zone above the water level or within the tidal zone?

Penetration: Does enough chemical penetrate into the concrete?

Depending on the result of the investigation, either a corrosion mitigation technique can be considered (e.g. galvanic anodes) or to combine the corrosion inhibitor with another surface treatment.

4.2.2 CHLORIDE – TWO LEVELS OF PROTECTION

A hydrophobic impregnation used in combination with a corrosion inhibitor will provide two levels of protection.

The hydrophobic impregnation will prevent liquid water penetration, whilst allowing water vapour to evaporate. This characteristic of a hydrophobic impregnation allowing the concrete pores to dry out will further enhance protection of embedded steel reinforcement.

It is recommended a deep penetrating hydrophobic impregnation applied in sufficient quantity should achieve a penetration depth of at least 4 mm for structures exposed to de-icing salts. For marine structures (splash and tidal zones) the hydrophobic impregnation is recommended to achieve a penetration depth of 5 mm. These penetration depths will provide an effective barrier against chloride ingress and chloride migration as demonstrated by Zhao and Wittmann[7] and Wittmann and Gerdes[8].

A computer software developed by NIST (National Institute of Standard and Technology) in the United States can predict the design life of a structure based on the chloride diffusion coefficients of treated and untreated concrete for varying thicknesses of concrete cover (http://ciks.cbt.nist.gov/~bentz/menu0002.html) [9]. Alternatively, by varying the cover thickness it can predict the equivalent concrete cover the protection system can reinstate.

The direct influence of corrosion was shown by subjecting cracked beams to regular cycles of salt water ponding and measuring the resultant steel corrosion activity (refer to figures 3). Beams treated with sufficient quantity of deep penetrating hydrophobic impregnation, even when applied before the cracks had occurred, proved to significantly reduce the initiation of corrosion by drying out the concrete pores surrounding the reinforcement bars and by limiting the access of chlorides.

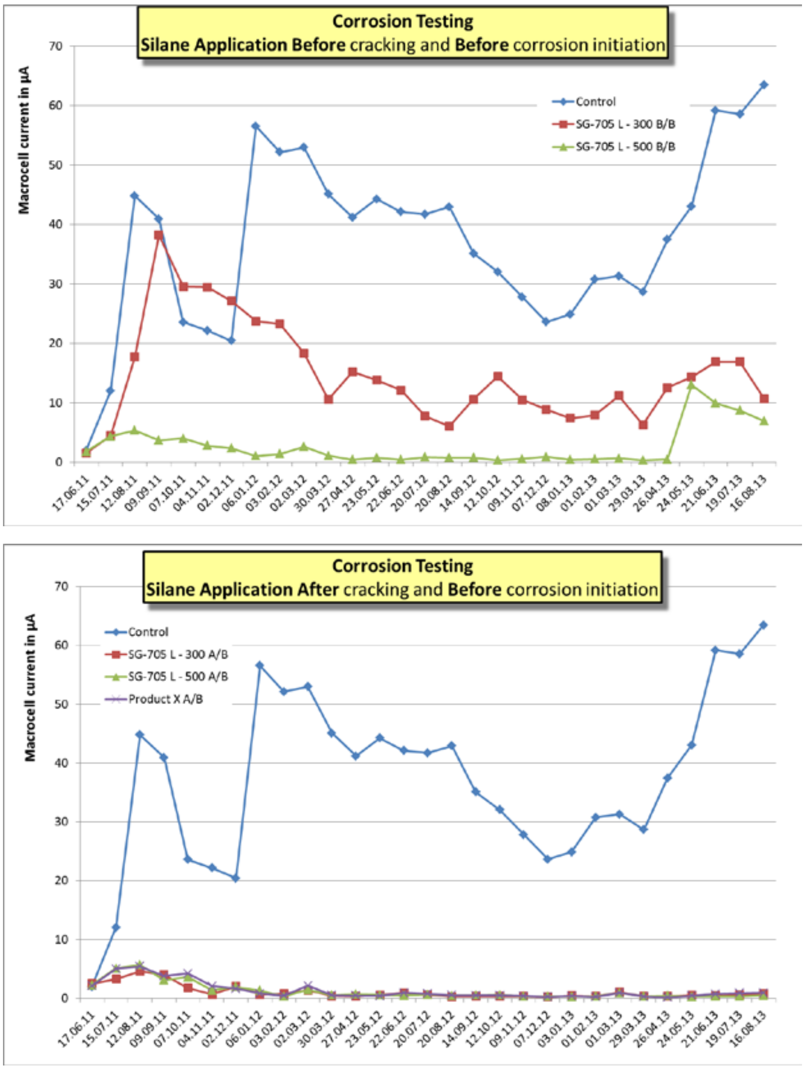


Figure 3: Corrosion activity as per ASTM G 109-07 modified

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6 LEGAL NOTE

7 KEY WORDS

Low cover, durability, reinforced concrete, fire protection, Sikagard, Sika Unitherm, Sika MonoTop, protective coating, corrosion inhibitor, hydrophobic impregnation

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