Surface Applied Corrosion Inhibitor for Rehabilitation of RC Structures

Dr. B. Abdelrazig
Sika Services IMEA, Dubai, UAE

ABSTRACT: The objective of this paper is to introduce a novel technology & present test results obtained from the field on the performance of a Surface Applied Corrosion Inhibitor (SACI) based on amino alcohols. SACI can be used as part of a repair and rehabilitation strategy as well as corrosion protection of reinforced concrete structures. It is shown to delay the onset of corrosion, reduce incipient anode formation and/or reduce the corrosion rate in an economical way. Monitored projects dating back for up 15 years will be discussed for building & bridge structures that show performance of inhibitor. Conventional and post-tensioned steel bridge structures have also been treated and monitored to start with. The paper draws data from the Sustainable and Advanced Materials for Road Infrastructure (SAMARIS) work programme during which monitoring of these bridges had been reactivated to allow access to longer term data.

1. INTRODUCTION

1.1 SACI for restorative & Preventive Applications

Sika has been active since the 1970's in the development of Amino Alcohol based corrosion inhibitors and this resulted in the granting of worldwide patents. This knowledge has led to further developments and the innovative FerroGard inhibitor technology. The admixture developed for preventive application is based on an organic film forming amino compound. Amino film forming inhibitors have a proven track record in the protection of oil and gas pipelines as well as the protection of packaged and stored machinery to prevent the deterioration of machined surfaces. The commercial product affords no risk to health and safety, rated toxicity free, and show no detrimental effects on concrete. The product for fresh concrete (admixture) has some plasticizing effect and only slightly retarding making it ideal to tolerate and benefit from elevated temperatures. It is compatible with all cements and cement replacement materials.

The Sika proprietary impregnation for surface application is amino alcohol based and has a synergistic effect, combining the benefits of both the anodic and cathodic types. It works as follows, Marazzani (1999), Brundle et al. (1996), Vogelsang (1996):

- Penetrates the concrete mainly through capillary suction.
- Forms an adsorbed chemical layer 100-1000 Angstroms thick on the surface of the steel rebar, reducing iron dissolution at anode and oxygen access at cathode.
- Displaces hydroxides on the steel surface in carbonated concrete & chlorides on the steel surface.

The above results in current densities that is negligible. At this stage it is important to recognize that corrosion inhibitors are not miracle cures that stop corrosion in its tracks, rather they buy time to the owners, specifiers and contractors and offer a cost effective means of extending a structure's life. This concept is demonstrated in Figure 1 below:

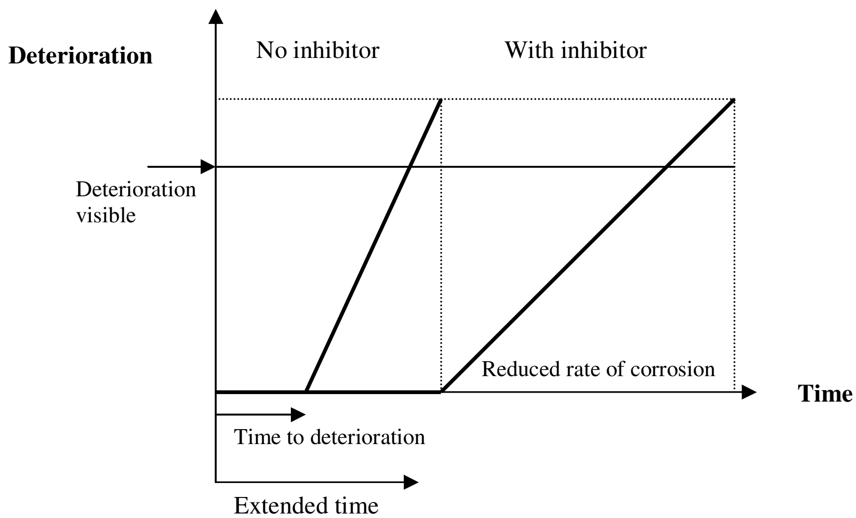

Figure 1: Concept of Extending of the service life of RC structures with corrosion inhibitor, Laamenen & Byfors (1996)

The product is suitable as preventive or restorative measure in buildings, bridges, tunnels, marine structures, tanks, towers, car parks and reinforced concrete pipelines. It is normally applied as part of a complete corrosion management strategy incorporating cementitious repairs, leveling mortars and protective coatings. One of the benefits of the corrosion inhibitor is the reduced breakout of the carbonated or chloride contaminated structurally sound concrete. Only cracked or spalled concrete requires removal. Once the local repairs have been carried out, the corrosion inhibitor can be applied.

The admixture is applied similarly to a hydrophobic impregnation. Ideally the substrate should be clean and dry with surface contaminants removed. A consumption of 0.5 kg/m^2 is recommended to be applied by low pressure spray, roller or brush in 3-5 applications allowing an hour or so between each application. If required to apply a surface coating after the inhibitor treatment, the inhibitor residue will need to be first removed from the concrete surface with high pressure water/grit blasting depending on the type of overcoating material .There are no reported adverse effects on the durability and integrity of the reinforced concrete, nor does the application constitute any more of a health and safety risk than more conventional repair and protection techniques. Qualitative control tests for the application of the inhibitor may be conducted on site using Sika Qualitative Colour Test. This test procedure is based on chromatography and is available as a portable testing kit. Off site laboratory testing can also be utilized using conventional qualitative or quantitative tests. Site trials and experimental test results have shown that when Sika impregnation is applied to a concrete surface, it can penetrate at between 2.5 and 20 mm per day and up to a depth of 80mm at 28 days. Studies of transport mechanism have yielded depth profiles showing a concentrated band of FerroGard passing through the cover concrete to the embedded steel. This penetration has occurred in a matter of days irrespective of the orientation of the application. There is no doubt that penetration is a subject of permeability and the denser the concrete substrate the more time the inhibitor will take Mulheron (1999), Wolfseher & Partners (1997).

1.2 The SAMARIS Project

The SAMARIS programme was set out in 2004 with the objective of formulating guidelines for specifiers, asset managers and other end users of surface applied corrosion inhibitors to use these treatments in locations where they have a “managed expectation” of being successful. The final recommendations are published as SAMARIS Report D25a in 2006, to which the end user is referred.

The SAMARIS reports dealing specifically with corrosion inhibitors were produced by the Work Package WP13 team of contractors and subcontractors to the contract. The Work Package was led by University College Dublin. The other contractors were Sika, Transport Research Laboratory; ZAG – Slovenian National Building and Civil Engineering Institute. Subcontractors were Cardiff University, C-Probe Systems Limited and Structural Healthcare Associates. Several public organizations in the United Kingdom granted access to their structures for testing and re-testing purposes and permitted publication of data arising from the tests of their structure. In the USA owners of structures allowed reference to unpublished data on their structures. This report presents findings from existing and newly-generated data from field experience on the use of corrosion inhibitors in a variety of circumstances. Data from a number of case studies was reviewed to allow comment on various aspects of the appropriate use of inhibitors in practice, related to aspects identified in the literature review and laboratory studies. In some previously treated and instrumented structures the monitoring was reactivated in the SAMARIS project to allow access to longer-term data than that which could be generated in from studies in the course of the SAMARIS Project timeframe. As there are hundreds of reference projects Worldwide, 10s of which were monitored around, 3 structures, Fleet Flood Span Bridge (chloride and incipient anode); Clifton New Bridge (chloride and post-tensioning); and Olympia House (chloride and carbonation) are reported in this paper.

2. PERFORMANCE MONITORING

The best way to determine the effectiveness of any corrosion inhibitor is by comprehensive corrosion rate monitoring on actual field installations. Half cell potentials may show very little differentiation, if any, as mixed inhibitors affect both cathode and anode equally resulting in no change in corrosion potential. Comprehensive corrosion monitoring involves collecting data from tests using linear polarization techniques, with embedded or surface mounted probes. Interpretation and analysis of the data should only be made by qualified personnel who specialize in the corrosion of reinforced concrete, Jones & Morlidge (2003). Corrosion rate monitoring can also provide an early warning prior to any renewed onset of significant steel corrosion in non overcoated FerroGard applications. This would then allow the level of the inhibitor to be replenished, thus ensuring the integrity of the protective film. Extensive laboratory and on site tests have shown that the inhibitor has successfully retarded the onset of corrosion and have been shown to be effective in concentrations of chloride ions up to 2% by weight of cement at the depth of the reinforcement, Jones & Morlidge (2003), Macdonald Report (1996). Many hundreds of concrete structures Worldwide, including post tensioned, have been successfully treated with Ferrogard impregnation as part of a complete corrosion management strategy which involved many other Sika repair products. In some of these structures the inhibitor was recommended by independent consultants who installed and managed comprehensive corrosion monitoring systems that have been running for years collecting long term corrosion data, C-Probe Tech (2010). Performance monitoring is a useful addition to the mitigation scheme and should be considered (where budgets permit) for several reasons; these are:

- To assess corrosion rate reduction from untreated to treated conditions
- To assess the continued performance of the treatments
- To plan when re-treatment may be necessary as part of a proactive planned preventative maintenance strategy.

Proof of performance can be split into three aspects:

(i) Has the corrosion inhibitor penetrated the concrete cover to reach the level of reinforcement?
(ii) If so, has the corrosion inhibitor effected electrochemical change in terms of reduction of corrosion rate from untreated condition?
(iii) Is the corrosion inhibitor acting as a barrier to any ongoing negative effect of environment?

Item (i) can be assessed (with amino-based inhibitors) as a penetration test that is based on chromatography techniques. Item (ii) can be assessed using embedded corrosion rate probes positioned to represent the structure as a whole. Item (iii) can be assessed using the corrosion potential response from the same corrosion rate probes. These performance indicators were used in the field trials that featured in the SAMARIS Work Package on SACI, some of which are discussed in this paper.

3. CASE STUDIES

3.1. Fleet Flood Span Bridge

3.1.1 Project Description: Fleet Flood Span Bridge carries the A1 trunk road in the United Kingdom and is one of many flood relief structures in the area.
3.1.2 Problem Description & Sika Solution: The bridge was the subject of multiple concrete repairs undertaken to the trestle and abutment sub-structures over many years, often at a frequency of less than 5 years between maintenance interventions. The repairs were required as a result of chloride-entrained water leaking through joints from de-icing salt water runoff. The formation of incipient anodes around the newly patched concrete resulted in premature failure of the repairs and it was decided by the managing agent for the UK Highways Agency in 2001 to try to mitigate this issue by using surface-applied corrosion inhibitors with the intended re-repair of the sub-structures. Measurements of corrosion rate using linear polarisation resistance measurement were taken manually up to 2002 and then reactivated as part of the SAMARIS project in 2005.
3.1.3 Performance: Three aspects of the case study were examined through data generated within a repair, immediately adjacent to a repair and at least a metre away.

i) Within a repair patch, where it may be assumed that the repair material will contribute significantly to the corrosion rate reduction.
ii) Within 150mm of the repair patch, where incipient anode activity may be anticipated.
iii) At a point >1000mm from any repair patch, that can be regarded as parent concrete for assessment of inhibitor performance on structure away from damaged areas.

A summary of the data recorded within the repair patch at four time steps is presented in Table 1 below:

Table1: Corrosion penetration rate within patch repair (comparison within patch)

Location	Probe Ref.	Corrosion Penetration Rate (µm/year) at time interval after inhibitor application			
		Base readings	9-month	27-month	57-month
North Abutment	NA3	54.0	0.64	2.20	0.94
North Trestle	NT2	25.6	0.30	0.44	1.77
South Trestle	ST4	3.63	0.19	0.03	0.00
South Abutment	SA3	6.49	0.90	1.74	1.20

Note: The 57-month reading of 0.00 recorded for ST4 is viewed not as actual zero corrosion rate but a value beyond the measurement of the instrumentation.

Table 2 below summarizes the performance of the inhibitor adjacent to the patch repair:

Table 2: Corrosion Penetration Rate, adjacent to patch repair (Incipient anode risk)

Location	Probe Ref.	Corrosion Penetration Rate (µm/year) at time interval after inhibitor application			
		Base readings	9-month	27-month	57-month
North Abutment	NA1	9.54	3.83	3.66	1.61
North Trestle	NT3	5.65	5.15	2.05	2.57
South Trestle	ST2	4.03	2.58	0.39	0.43
South Abutment	SA1	7.85	6.40	0.69	0.72

A summary of the data recorded from a zone of parent concrete is presented in Table 3:

Table 3: Corrosion Penetration Rate, parent concrete (Parent concrete steel response)

Location	Probe Ref.	Corrosion Penetration Rate (µm/year) at time interval after inhibitor application			
		Base readings	9-month	27-month	57-month
North Abutment	NA2	37.1	3.37	3.06	2.51
North Trestle	NT1	1.42	0.10	0.14	0.15
North Trestle	NT4	17.0	1.30	0.94	0.57
South Trestle	ST1	3.24	0.36	0.67	0.63
South Trestle	ST3	3.20	0.92	0.30	0.19
South Abutment	SA2	44.8	0.75	3.73	0.32

3.1.4 Summary: It is clear that in all three scenarios the corrosion rates have been reduced and maintained at low values since first treatment with the SACI. Another indicator of performance is that the Owner has not been required to re-repair any areas or needed to perform repairs to new areas since the inhibitor treatment has been applied.

3.2 Clifton New Bridge

3.2.1 Project Description: Clifton New Bridge is a post-tensioned segmental bridge in the UK built in the 1970's that is largely in good condition today.

3.2.2 Problem Description & Sika Solution: A specific problem arose with leaking water drainage guttering within the box sections that failed to serve its purpose of taking rainwater (entrained with deicing salts) from the deck and leaked onto the top of the post-tensioned box sections in six isolated locations along the structure. The chloride concentrations were sufficient to cause localized cracking and spalling to the top layer of three layers of tendons. The middle layer was showing early signs of damage also. The bottom layer was in good condition.

The solution chosen was to remove all delaminated concrete from around the top tendons but to leave chloride-contaminated but good concrete in position. The most obvious corrosion mitigation solution would have been to install an impressed current cathodic protection system but given that most of the chloride contamination had been removed with the delaminated concrete, it was then decided to apply corrosion inhibitor within the breakout area, also to include an inhibitor within the repair material and also once the repair was cured then to apply additional surface-applied corrosion inhibitor to the top and side of the concrete box.

3.2.3 Performance: Monitoring was added to the top, middle and bottom tendon layers for all six repair locations. The selected trend in Figure 2 shows the very low activity throughout. High positive measurements of potential confirmed this trend.

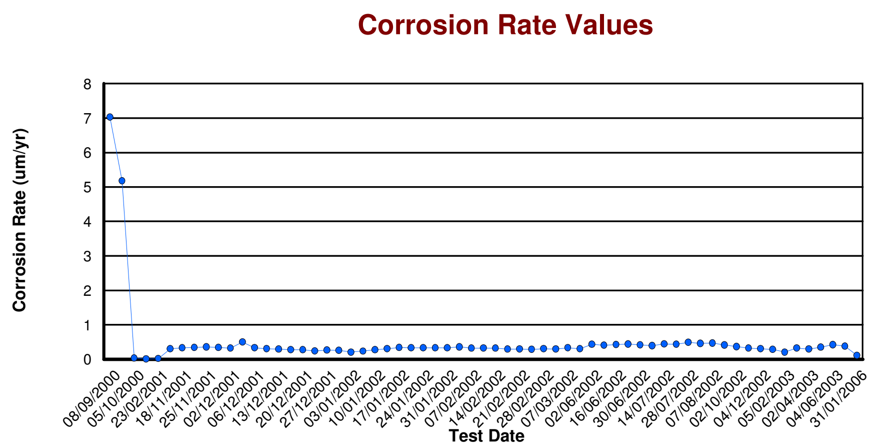

Figure 2: Corrosion Penetration Rate of SACI in Clifton Bridge

3.2.4 Summary: The success of the overall repair strategy over a sustained period is apparent. The use of SACI for post-tensioned steel protection is especially safe given that the electrochemical potential cannot be affected and as such hydrogen embrittlement is not a risk , BAM Test Report (2004).

3.3 Olympia House:

3.3.1 Olympia House is United Kingdom Government office constructed in the 1970's as a reinforced concrete frame building with external precast panels and internal reinforced concrete stairwells built. The building is located in Newport on the coast of South Wales and as such is subjected to a marine environment

3.3.2 Problem Description and Sika Solution: The building was suffering from carbonation induced damage to the precast panels with low cover to reinforcement and chloride induced damage to the internal stairwells due to heavy pedestrian traffic bringing in deicing salts in winter. It was the subject of concrete repairs in 1996 with the additional strategy to incorporate SACI to mitigate future corrosion. This treatment was also supplemented externally with an anti-carbonation coating but the internal stairwells remained bare concrete surfaces following repair and treatment.

3.3.3 Performance: This building was the first to receive embedded corrosion rate monitoring to assess ongoing performance of the protection systems and therefore provide data over a relatively long timescale. The tests were conducted pre-treatment and post-treatment by manual assessment using LPRM. It is to be noted that in one position the measured value was still high some 12-months following first measurement and that all subsequent measurements of all positions demonstrate significant reduction in corrosion rates that have been maintained for the full period from completion in January 1997 to November 2005.

3.3.3.a. Carbonated concrete: A summary of the data recorded from the zone of carbonated concrete is presented in Table 4. Data from probes on three levels are presented.

Table 4: Corrosion Penetration Rate, adjacent to patch repair

Probe Ref.	Corrosion Penetration Rate (µm/year) at time interval after inhibitor application				
	Base readings	12-month	36-month	75-month	106-Month
Level 3W.4	56.1	5.6	0.53	0.63	0.83
Level 5N.1	35.6	1.5	-	0.27	0.08
Level 5E.2	99.0	2.7	0.07	0.82	1.17

3.3.3b Chloride contaminated concrete: A summary of the data recorded from the zone of chloride-contaminated concrete is presented in Table 5. Data from probes on four levels are presented.

Table 5: Corrosion Penetration Rate, adjacent to patch repair

Probe Ref.	Corrosion Penetration Rate (µm/year) at time interval after inhibitor application				
	Base readings	12-month	36-month	75-month	106-Month
Level 5N.3	100 (see note)	4.3	0.23	0.14	0.09
Level 5N.4	100 (se note)	77.3	5.20	5.24	3.81
Level 7S.1	86.9	4.1	0.31	0.71	0.43
Level 7S.2	51.3	4.9	0.62	0.60	0.41

Note: The Base measurements for 5N.3 and 5N.4 were measured as 756 and 449 microns/ year respectively but were measured when the mortar around the probe was still curing. This is alleviated in more recent projects by measuring base data at least 24-hours after placement. A more realistic figure of no more than 100 microns/ year has been input given the 12-month responses following treatment and other measured values from similarly situated probes.

3.3.4 Summary: It seems clear from this data that inhibitors respond to carbonation-related corrosion more rapidly than chloride-related corrosion damage although once established the measured corrosion rates are very low in both circumstances. The owner wished to use a strategy that would achieve a maintenance-free 15 year service life for the repaired structure. This expectation has been met to date.

4. Conclusions

4.1 Amino alcohol based FerroGard corrosion inhibitors developed by Sika are cost effective corrosion control measures for both chloride as well as carbonation induced corrosion.. They are shown to delay the onset of corrosion, retard incipient anode formation and prolong the service life of the structures by significantly reducing the corrosion rates.
4.2 Repair or replacement methods must be the most permanent solution, but may not be practical in all cases. For both chloride and carbonation corrosion damage and within the spectrum of measures discussed in this paper concrete repair and protection with organic corrosion inhibitor as a part of a repair/protection strategy can offer cost effective options that may prove valuable in many situations.
4.3 There are many permutations to allow for in making judgement on the use of these treatments as part of an integrated strategy or any other corrosion protection measures. There are clear requirements for expertise in corrosion inhibitor & monitoring to satisfactorily control any risk. This perhaps may best be achieved by a proactive maintenance strategy based on performance monitoring.

5. References

BAM test Report, 2004 "Federal Institute for Materials Research and Testing (BAM) 12200 Berlin, 03-23.

Brundle, CR, San Jose, CA, Grunze, M, 1996 the use x-ray Photon Spectroscopy (XPS) and Secondary Ion Mass Spectroscopy (SIMS) Studies of Amino Alcohol Exposed to Steel Surfaces, *Surfaces and Interface Analysis*, 549-563.

C-Probe Technologies Ltd, 4 The terrace, Rugby Road, Lutterworth UK LE17 4BW, e mail: enquiries@ c-probe.com, web:www.c-probe.com.

Jones, G and Morlidge, 2003, JR, Performance Management of Inhibitors treatments for Reinforced Concrete Structures, UK Corrosion.

Laamenen, PH, and Byfors, K, 1996, Corrosion Inhibitors in Concrete – AMA (alkanolamines) – Based Inhibitors – State of the art Report, Nordic Concrete Research, No. 19,, pp 29-40.

Marazzani, B. 1999, Testing of the corrosion-inhibiting impregnation Sika Ferrogard 903 on carbonated slab containing slightly to moderately corroded rebars, Madrid, *Proc. of the Int. Workshop Mesina*, 18.1-18.10.

Mott Macdonald, 1996, Sika FerroGrad 901 and 903 corrosion Inhibitors, Evaluation of Test Programme.

Mulheron, M, 1999, Corrosion Inhibitors for High Performance RC Structures, Paper presented at SCI Conference, University of Surrey.

Vogelsang, J, Investigations on Concrete Admixtures using Electrochemical methods, Part 2, Inhibitor Testing, Experimental Details and Results.

Wolfseher & Partners AG, 1997, Sika FerroGard 903 Corrosion Inhibitor, Materials technology Test, Baar, Report No 96.144.11.