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MONOLEVEL FC⁺
MCI[®] Modified Fairing Coat
Site Evaluation



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Contents

	Summary	1
1	Introduction.	2
	1.1 Background	2
	1.2 Scope of Study	2
	1.3 Description of the Structure	3
2	Fairing Coat Evaluation	5
	2.1 Pre-Application Survey	5
	2.2 Concrete Condition	5
3	Coating Trial	8
	3.1 Surface Preparation	8
	3.2 Application	8
	3.3 Sampling	8
	3.4 Analysis	8
4	Results & Discussion	10
	4.1 Diffusion Coefficient for Inhibitor Ingress	11
	4.2 Influence of Exposure Conditions	11
5	Conclusions	12

Summary

SED were commissioned by Flexcrete Limited to develop and undertake a series of site evaluations to establish the performance of a novel fairing coat modified by the addition of migratory corrosion inhibitor (MCI[®]).

To evaluate the migration of corrosion inhibitor from fairing coat to substrate a number of tasks were identified including:

- Selection of three test sites representing external exposed, external sheltered and internal exposure environments.
- Characterisation of the substrate concrete.
- Surface preparation and application of the modified fairing coat.
- Monitoring the depth of inhibitor ingress over a period of 18 weeks.
- Analysis and interpretation of the data.

A series of tests were carried out under the supervision of Dr Paul Lambert (as Mott MacDonald Visiting Fellow) to establish the condition and nature of the concrete in the three test locations. Non-destructive tests, such as cover, were carried out on the actual test locations while semi-destructive tests such as carbonation depth evaluation were performed on adjacent areas of concrete.

Inhibitor analysis was performed at 1, 5 and 18 weeks after application and consisted of drilling small diameter cores from which samples could be obtained representing depth gradients of 10 mm up to a maximum of 50 mm. Additional control samples were also obtained from the fairing coat and parent concrete.

The concentration of inhibitor was calculated as a weight percentage relative to the original render content of 0.03%. The concrete substrates showed a residual level of amine or ammonia contamination of between 0.002 and 0.003 percent by weight which was taken into account during subsequent numerical analysis of the results.

The application of the MCI[®] modified fairing coat resulted in inhibitor being detected at significant depths of cover within a few days and to be present at the depth of the reinforcement after 18 weeks.

The three exposure conditions showed some variation in performance that could be explained by either the extent of weathering to the original surface or the exposure conditions during the trial, with the best performance in terms of inhibitor ingress being observed for the external-exposed condition.

At the time of reporting the three test panels remain in good condition and are available for further evaluation should it be required.

MCI[®] is a registered trademark of Cortec Corporation

1 Introduction.

1.1 Background

SED were commissioned by Flexcrete Limited to develop and undertake a series of site evaluations to establish the performance of a novel fairing coat modified by the addition of migratory corrosion inhibitor (MCI[®]) with the product name Monolevel FC⁺. Following discussions between SED and Flexcrete, the following study was proposed to evaluate the migration of inhibitor from the fairing coat into a number of representative substrates.

1.2 Scope of Study

To evaluate the migration of corrosion inhibitor from fairing coat to substrate the following tasks were identified.

Task 1

Three test sites were selected for the investigation, representing locations classified as external exposed, external sheltered and internal. The sites have been made available at Sheffield Hallam University's Psalter Lane Campus.

Task 2

Prior to commencement of the trials the concrete at the test sites was characterised with respect to nature and quality by carrying out appropriate tests, specifically cover, carbonation, chloride ion concentration, strength, density porosity and permeability.

Task 3

Application of the fairing coat material, incorporating corrosion inhibitor, in accordance with the manufacturer's specifications. The coating was applied by experienced contractors under the supervision of a Flexcrete technical representative (John Bailey).

Task 4

Monitoring of the test sites at 1, 5 and 18 weeks. At each test age, a series of small cores was obtained representing the cover zone (up to 50mm). Further control samples for the fairing coat and substrate were also obtained and analysed.

Task 6

Analysis of data including the determination of diffusion coefficients for the inhibitor.

For the purposes of this study it is assumed that an inhibitor concentration of 0.005 percent by weight is sufficient to provide additional protection to steel in carbonated concrete.

The study was carried out under the supervision of Dr Paul Lambert in his role of Mott MacDonald Visiting Research Fellow.

1.3 Description of the Structure

Building Block B located at the Psalter Lane Campus is a 3 storey concrete encased steel framed building with glazed roof lights which increases the structure to 5 storeys.

The structure is built in an old quarry, adjacent to the cut face of the quarry walls. This offers environmental protection to the rear (south) elevation of the property, whilst the front (north) elevation faces the campus car park and is more exposed (see Figures 1 & 2). The structure was constructed in the early 1960s. The envelope is clad in part by pre-cast concrete panels with an exposed aggregate finish, glazing and partially by brickwork cladding.



Figure 1: North Elevation.

The main vertical structural members are concrete encased steel stanchions and it is these columns that were selected for the trial applications. The same form of column is also employed internally. A number of the external columns have already suffered damage due to corrosion of the secondary reinforcement; particularly in areas of low cover (see Figure 3).



Figure 2: South Elevation.



Figure 3: Typical Damage to Columns.

2 Fairing Coat Evaluation

2.1 Pre-Application Survey

Prior to applying the modified fairing coat it was necessary to evaluate the condition and structure and select areas for the trial. As part of the survey the elements were subjected to a hammer rapping survey to determine the integrity of the section of the element being investigated.

On the basis of this initial survey it was possible to select three columns for the trial representing a range of exposure conditions, namely:

- External Exposed - North Elevation
- External Sheltered - South Elevation
- Internal - Interior Column.

In each case, a section of column face was selected where there was no evidence of past repairs or current damage. The internal columns appear to have been maintained in a coated condition from new and there is evidence of a scrape coat to fill any open porosity prior to the initial coating. The external-exposed columns have been coated with masonry paint but this is now badly weathered and affords little if any protection to the concrete. The external-sheltered columns are uncoated.

2.2 Concrete Condition

A series of tests were carried out to establish the condition and nature of the concrete in the three test locations. Non-destructive tests, such as cover, were carried out on the actual test locations while semi-destructive tests such as carbonation depth evaluation were performed on adjacent areas of concrete.

Values were obtained for the following factors:

- Cover to Reinforcement (BS 1881:Part 204:1988)
- Depth of Carbonation (BRE Digest 204:1995)
- Chloride Ion Content (BS 1881:Part 124:1988)
- Cement Content (BS 1881:Part 124:1988)

Other factors such as compressive strength and water-cement ratio were evaluated on the basis of visual examination of small diameter cores. The cores were also employed to evaluate density, water absorption and ISAT in general accordance with the appropriate sections of BS 1881 (Parts 114, 122 and 208 respectively). The results obtained are shown in the following tables.

Location	Depth of Cover (mm)		
	Minimum	Maximum	Average
EXTERNAL - EXPOSED	9	47	31
EXTERNAL - SHELTERED	7	44	29
INTERNAL	10	38	26

Table 1: Results of Covermeter Survey

Location	Depth of Carbonation (mm)	
	Minimum	Maximum
EXTERNAL - EXPOSED (degraded masonry paint)	5	30
EXTERNAL - SHELTERED (uncoated)	7	25
INTERNAL (well-maintained coating from new)	0	2

Table 2: Results of Carbonation Testing

Location	Chloride Ion % mass of sample	
	Minimum	Maximum
EXTERNAL - EXPOSED	0	0.017
EXTERNAL - SHELTERED	0	0
INTERNAL	0	0

Table 3: Results of Chloride Analysis

Soluble Silica %	Calcium Oxide %	Cement Content %
3.50	10.52	16.31

Table 4: Cement Content (blended sample)

Location	Density (kg/m ³)	Water Absorption (30 minute, %)	ISAT (30 minute, ml/(m ² .s))
EXTERNAL - EXPOSED	2110	5	0.5
EXTERNAL - SHELTERED	2210	3	0.4
INTERNAL	2250	2	Not Tested

Table 5: Other Results

Based on the data available it is estimated that the concrete has an original water-cement ratio of around 0.6 and a current compressive strength of approximately 40 MPa.

The data obtained indicates the concrete to be of a typical grade and condition for its age and application and is considered representative of the type of substrate to which a material such as the modified fairing coat might be applied.



Figure 4: Surface Preparation by Water Jetting

3 Coating Trial

3.1 Surface Preparation

Prior to applying the fairing coat it was necessary to carry out a degree of surface preparation. For the external columns this consisted of medium pressure water jetting (Figure 4) which also removed the remaining weathered masonry paint from the North Elevation. For the painted internal column an industrial hot air gun was employed to remove the various paint layers.

3.2 Application

The fairing coat was mixed and applied in accordance with the Manufacturer's recommendations and under the supervision of their technical representative. The coating was applied by trowel to a thickness of approximately 3 to 6 mm.

Application to all three test areas was carried out on 7th March 2002 and the finished coatings are shown in Figure 5.



Figure 5: Test Areas (l-r): External-Exposed; External-Sheltered and Internal

3.3 Sampling

Sampling was performed 1, 5 and 18 weeks after application and consisted of drilling small diameter cores (nom. 25 mm diameter) from which powdered samples were obtained, representing depth gradients of 0 to 10 mm, 10 to 20 mm, 20 to 30 mm, 30 to 40 mm and 40 to 50 mm (Figure 6 and 7). Additional control samples were also obtained from the fairing coat and parent concrete.

3.4 Analysis

The powdered samples were weighed into glass bottles with a measured volume of distilled water and vigorously agitated. It was observed that a minimum of 24 hours

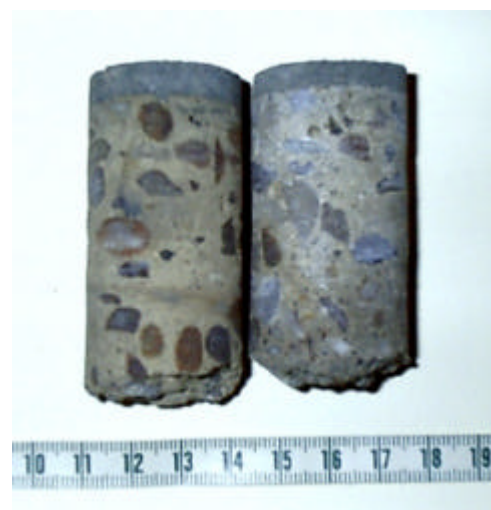
was required to fully extract the inhibitor. The resulting solution was filtered and subjected to chemical analysis for the presence of the inhibitor, as represented by a quaternary ammonia compound.

The concentration of inhibitor was calculated as a weight percentage relative to the original render content of 0.03%. As anticipated, the concrete substrates showed a residual level of amine or ammonia contamination of between 0.002 and 0.003 percent by weight.



Figure 6: Obtaining Cored Samples for Analysis

Figure 7:
Typical Cored Samples



4 Results & Discussion

The results obtained for the three locations at 1, 5 and 18 weeks are shown graphically in Figures 8, 9 and 10. The concentration of inhibitor is expressed as a percentage by weight of the sample.

The inhibitor concentration in the fairing coat has been assumed to be at the design level of 0.03% for the first two readings (Figures 8 and 9) but was determined at values of between 0.015% and 0.02% after 18 weeks exposure (Figure 10).

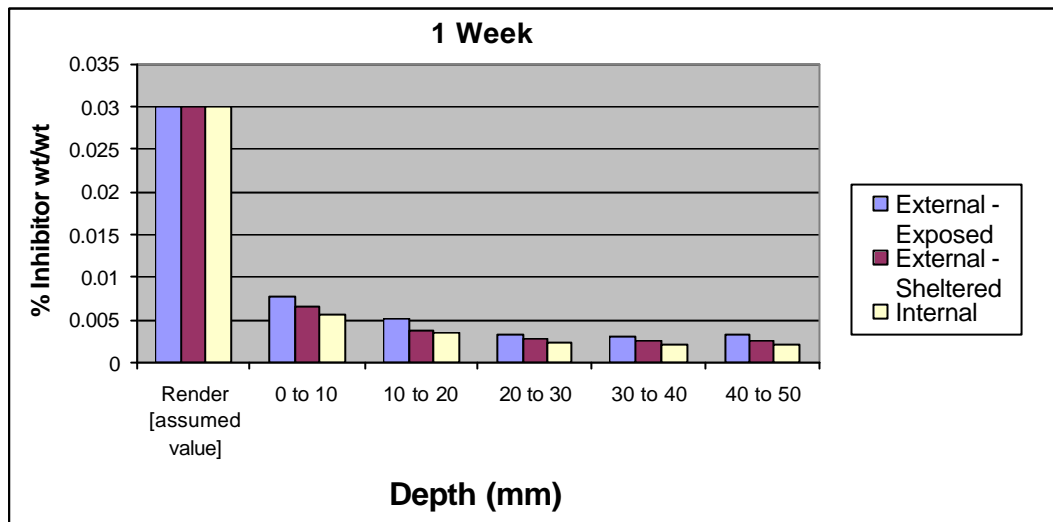


Figure 8: Inhibitor Gradient - 1 Week

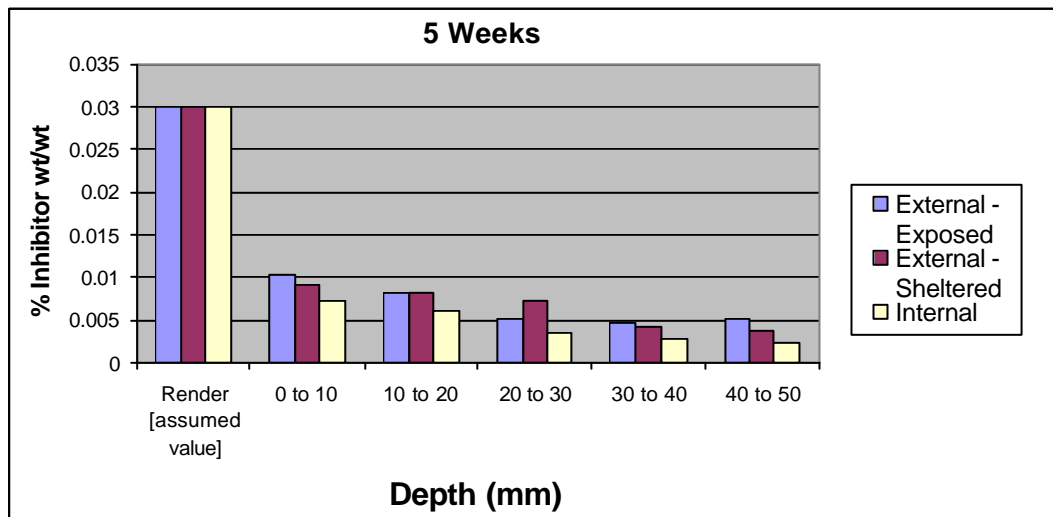


Figure 9: Inhibitor Gradient - 5 Weeks

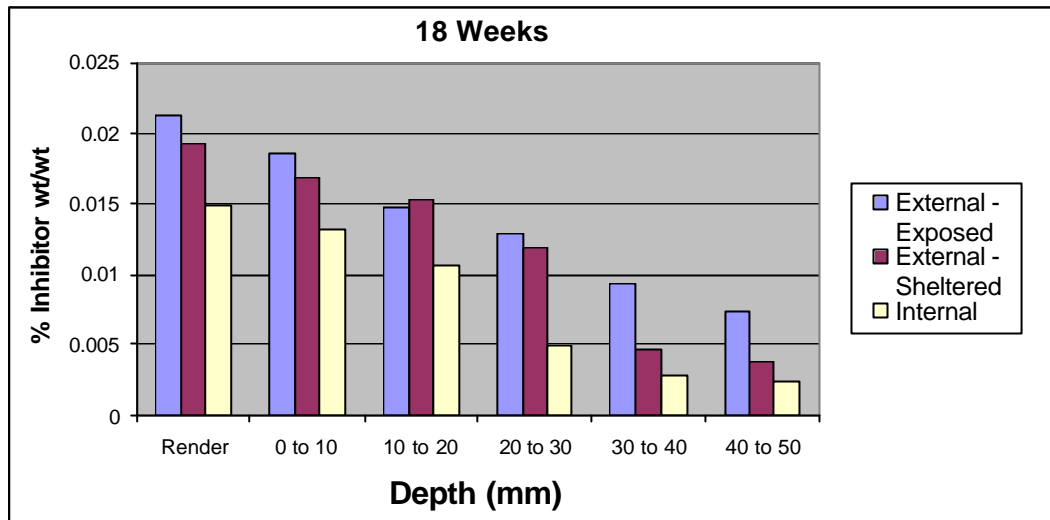


Figure 10: Inhibitor Gradient - 18 Weeks

4.1 Diffusion Coefficient for Inhibitor Ingress

By combining all the data it has been possible to calculate approximate values for the diffusion coefficient of the inhibitor on the assumption that Fick's Law applies. The initial value is around $1.8 \times 10^{-10} \text{ m}^2/\text{s}$ but after 18 weeks this reduces to $3.6 \times 10^{-11} \text{ m}^2/\text{s}$. These values can be compared with figures reported for chloride ion diffusion for concrete of similar quality which are typically in the range 10^{-12} to 10^{-10} .

4.2 Influence of Exposure Conditions

The results shown in Figures 8 to 10 indicate slight differences in the diffusion behaviour of the inhibitor dependant upon exposure condition. Most notably, the external-exposed test area generally achieved the highest rate of inhibitor ingress, followed by the external-sheltered with the internal area showing the lowest ingress.

It is considered likely that much of this difference is a result of the surface porosity of the test areas, with the highly weathered North Elevation being more open textured than the South. The internal panel had very low surface porosity (see Table 5), largely as a result of the application of a pore filler at the time of construction.

The variation of the inhibitor content in the render observed at 18 weeks may be partly due to the exposure conditions during the trial.

The internally exposed panel was essentially maintained at 20°C, 60% RH and therefore may have been expected to suffer the greatest losses from the fairing coat.

The external panels would have generally been in a cooler and more humid environment where lower losses of inhibitor from the fairing coat might be expected.

It should be noted that all three panels were uncoated for the purposes of the test but would normally be with a protective or aesthetic paint system.

At the time of reporting, all three test panels remain in place, are in sound condition and continue to provide additional protection to the treated areas.

5 Conclusions

- The application of Monolevel FC⁺ to representative concrete substrates resulted in inhibitor being detected at significant depths of cover within a few days and to be present at the depth of the steel at levels considered sufficient to offer protection after 18 weeks.
- Some variation in performance could be observed from the three exposure conditions selected. This could be partly explained by the extent of weathering to the original surface and partly by the exposure conditions during the trial. Specifically, for the uncoated fairing coat employed in these trials:
 - **External-Exposed** - weathered surface allowing rapid ingress of inhibitor.
 - **External-Sheltered** - moderately weathered surface resulting in slightly slower inhibitor ingress.
 - **Internal** - unweathered surface with filled porosity, held at room temperature and low relative humidity resulting in the lowest rate of ingress and greatest losses from the fairing coat.
- Values of diffusion coefficient for the inhibitor confirm that the initial rate of inhibitor ingress is high and reduces with time, as would be expected. The rate of ingress is within the range typically reported for chloride ions in severe environments.
- The treated areas have remained in sound condition with no delamination of the fairing coat and are available for further evaluation should it be required.