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Marine Matters

Marine Coating Testing
Five Years in a Tidal Stream

Final Report 2017
Coppercoat

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Solutions for
Sustainable Seas

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Specialties

Biofouling, Ballast Water, Ballast Water Treatment Systems, Marine Surveys, Marine Environment Assessment, Remote Sensing, Earth Observation, Harmful Algal Blooms.

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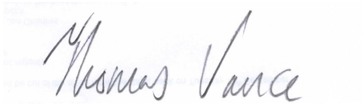
Author	Dr Tom Vance PML Applications Limited Prospect Place West Hoe Plymouth UK	
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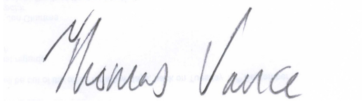
Approved By	Dr Tom Vance PML Applications Limited Prospect Place West Hoe Plymouth UK	

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1 Background and Executive Summary

- The aim of this work is to quantify marine coating performance during a five year *in-situ* exposure test in a tidal stream.

- At the time of writing, we understand this to be the longest coating trial of its kind. It provides unique insight into coating performance on a time scale similar to the predicted service intervals of marine energy devices.

- As part of the Energy Technology Institute's (ETI) ReDAPT project, two benthic pods were deployed in the Fall of Warness in Orkney, Scotland, at a depth of 40m, close to the Alstom turbine test site, on May 28th 2012.

- Both of the 3.5 tonne pods were fitted a range of antifouling and protective coating panels. These panels remained *in-situ* for 24 months until the end of the ReDAPT project. After 24 months, the south pod was recovered and sampled to meet the requirements of the ReDAPT project.

- In May 2014, it was agreed to extend the test by three years by maintaining the remaining pod to reach a total of 5 years continuous *in-situ* testing.

- The pod has been visually sampled each year during 2015 and 2016 using a Remotely Operated Vehicle (ROV) to confirm the pod was still in position and to provide a coarse measure of antifouling performance.

- In 2017, after five years in position in the tidal stream, the remaining pod was recovered and sampled. This report provides a summary of annual inspections and the end point analysis.

- All coatings showed signs of either damage, fouling or both after 5 years.

- Much of the fouling was caused by one species of barnacle, *Chirona hameri,* and a good predictor of success was a coating's ability to deter this species.

- Based on our section of ranking criteria Coppercoat scored 2 (out of 10) in terms of preventing fouling and damage at 24 months.

- After 60 months of testing Coppercoat was the best performing coating.

2 Methods

2.1 Pods

The experimental pods were fabricated for the ETI's ReDAPT project. A full description of their design can be found in the ReDAPT ME8.2 report. In summary, the pods were designed to be hard wearing, resistant to tipping in the tide, and able to support a number of coated panels in the tidal stream.

2.2 Panels

Most of the test panels were made of carbon steel to simulate the material used in most marine energy devices. However, one set of panels was made of glass re-enforced polymer (GRP) and coated with a glass flake epoxy coating, to simulate another commonly used material and coating combination.

The panels were fixed into bespoke panel holders before bolting to the pods, see Figure 1. The panels were held firmly in nylon plastic channels, with plastic spacers in between the panels and the ends of the panel holder. In this way, each panel was electrically isolated from all other panels and the panel holder.

No sacrificial anodes were used on the pod or the panel holders.

2.3 Coatings

2.3.1 Coating Selection

At the start of the ReDAPT project, Coppercoat was contacted and invited to supply coatings for the project. Coppercoat was provided with a description of the test environment and invited to submit its most suitable coating system for the test.

In addition to the coating supplied by Coppercoat, several other systems (manufacturer applied) were tested alongside a low cost self-polishing biocidal coating purchased from a local chandler and brush applied by the user following the manufacturer's instructions.

It was not possible to leave a panel uncoated to act as control, as this would have corroded away before the end of the test. Instead, a commercially available anticorrosive coating with no known inherent antifouling capability was brush applied in accordance with the manufacturer's instructions to one set of panels to act as a control.

2.3.2 Application Procedures

The coating application process and conditions can have a significant impact on the performance of a coating system. Consequently, it was decided that with the exception of the low cost self-polishing coating and the anticorrosive control, all coatings would be applied by the manufacturers. PML delivered the carbon steel panels to the manufacturer, and the manufacturer returned the coated panels back to PML for testing.

2.3.3 Coating Specification

All the available coating information for the Coppercoat system is listed below.

Table 1: Description and specification of the Coppercoat system as provided by manufacturer.

Name	Coppercoat
Technology Type	Biocidal copper filled epoxy resin
Anticorrosive	GP120 (DFT 250-300µm)
Top Coat	Coppercoat (DFT 250-300µm)
Pre-test Tot DFT	~350µm
Commercial availability	Available – Nov 2017
Notes	Manufacturer applied

2.4 Experimental Design

Each pod was fitted with 10 rows of panels, with each row consisting of ten test panels i.e. 100 panels in total per Pod, and 10 replicates of each coating per pod. The ten rows of panels were split between opposite sides of each pod meaning 5 rows (50 panels) were on opposite sides (see Figure 1). Each row consists of one panel of 10 different types of antifouling or protective coating treatments and controls.

Figure 1: Assembly of the pods and panel units in Orkney.

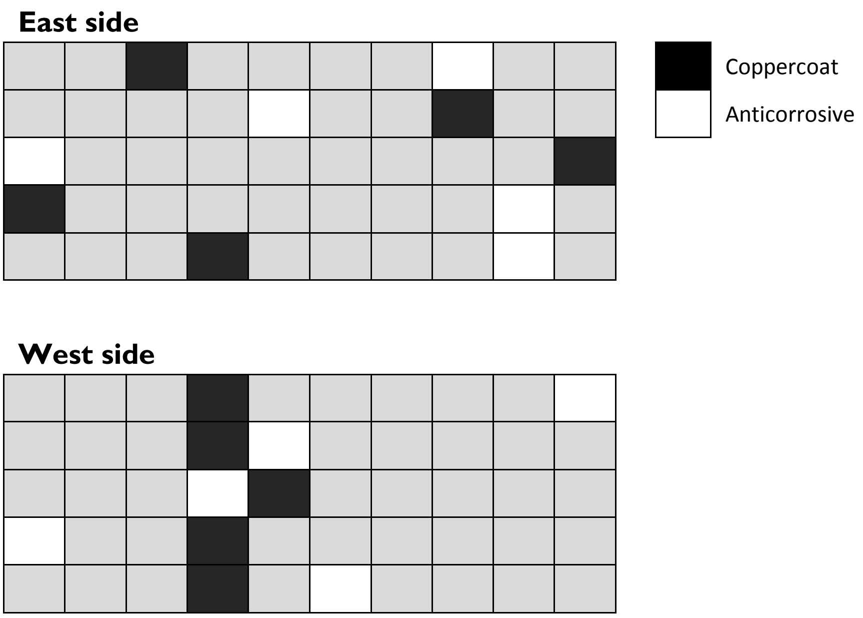

Figure 2: Diagram of panel layouts on east and west sides of East Lander, redeployed in 2014.

2.5 Pod Deployment History

In 2014, after 24 months exposure, the pods were recovered from the water. The South pod was disassembled and the panels returned to Plymouth Marine Laboratory for full analysis for the ReDAPT project. The East Pod was lifted, photographed and redeployed in the same location +/-2m.

Table 2: Summary of deployment history of the pods.

Task	Date	Total duration of test
Pods assembled and deployed	May 2012	0
Pods surveyed by ROV	May 2013	1 year
One pod recovered for ReDAPT project	May 2014	2 years
Remaining pod surveyed by ROV	May 2015	3 years
Remaining pod surveyed by ROV	May 2016	4 years
Remaining pod recovered	May 2017	5 years

2.6 ROV Survey

During 2015 and 2016, an ROV was used to check the position and integrity of the pod, together with capture of images which provided a coarse measure of percentage coverage of fouling on each panel, together with a visual assessment of the percentage coverage of damage to the coating if applicable.

2.6.1 Method for scoring panel fouling and damage from ROV footage

Scoring panels using ROV footage can only provide coarse data for preliminary analysis, and therefore results are limited in detail. Still images were captured of each panel directly from the ROV video footage.

Each still image for both years was assessed by the same in-house taxonomist to minimise sampling error. Percentage cover of visible organisms and damage to coating was estimated by eye on each panel. Estimates of percentage coverage were "calibrated" by revisiting previous scores for inter-year comparisons.

Scoring percentage cover as opposed to abundance (where all individuals are counted) is more appropriate in this instance as all species and corrosion can be assessed on a common scale, the extent of spreading organisms such as sponges is easily measured (J.A.Lewis, 1981). Scoring by eye as opposed to using more technical approaches has been shown to have less variation in accuracy than using random-point quadrats for example (Dethier *et al*, 1993).

It should be noted that "damage" encompasses a range of panel conditions, namely total corrosion of the coating and panel beneath, exposed tie-coats, and barnacle "bull-dozing" effects.

<u>References:</u>

Lewis, J.A., 1981. *A Comparison of Possible Methods for Marine Fouling Assessment during Raft Trails* (No. MRL-R-808). MATERIALS RESEARCH LABS ASCOT VALE (AUSTRALIA).

Dethier, M.N., Graham, E.S., Cohen, S. and Tear, L.M., 1993. Visual versus random-point percent cover estimations:'objective'is not always better. *Marine ecology progress series*, pp.93-100.

2.7 Coating Thickness

2.7.1 Measurement

Coating thickness data were compared within and between coating types at three time points (0, 24 and 60 months) pre-and post-deployment, to help assess the likely operational life of the coatings systems in the harsh test environment.

Coating thickness was assessed using an Elcometer® magnetic digital thickness gauge which was calibrated at 1300 microns and 126 microns to cover the expected dry film thickness range. Time zero thickness measurements were taken at a minimum of 10 points evenly distributed across each panel surface where possible, ensuring no point was closer than 1cm to the edge. These measures were then used to generate an average surface thickness per panel.

The same method was used at the other two time points (24 months & 60 months). Post deployment, heavy fouling or severe corrosion prevented thickness measures from being taken in some cases. Please note that sample sizes consequently vary post deployment and are reported in the Results Section.

Due to the requirements of the previous ReDAPT project, it was not always possible to take measurements on the exact same panels at each time point. Therefore inter-coating variability in coating thickness is unavoidably included in the data.

2.8 Species Specific Analysis

2.8.1 Sample preservation

The remaining pod was recovered from the test site and stored overnight in Kirkwall Harbour until sampling the next day. 24 hours after removal from the test site, the pod was removed from the water for the last time and destructively sampled within 1 hour in a nearby yard.

Digital photographs were immediately taken of all panels. The top three rows of side B were removed and each panel was separated from the panel holder, preserved in 70% ethanol, and returned to the Plymouth Marine Laboratory (PML) in Devon, UK, for taxonomic identification. The top three rows of panels were selected for species specific analysis as it appeared that mobile substratum had scoured much of the fouling off the bottom two rows of panels.

The remaining 7 panel holders were removed from the pod and returned to PML. The individual test panels were removed from their panel holders, re-photographed and dry stored for coating thickness analysis.

2.8.1 Assessment of Coating Performance

Coating performance was assessed by PML Applications' in house taxonomist. The panels were scored by placing a grid made of nylon monofilament fishing line attached to a plastic frame over each panel. The grid was made up of 100 x 1 cm^2 squares. The number of times each one of the following criteria was encountered in each square was recorded. Only organisms that were directly adhered to the panels were analysed. Thus mobile species and epiphytic organisms were not measured.

Table 3: Table of species specific assessment criteria.

Assessment Criteria	
Specific Category	Coarse Level Category
Chirona hameri	Barnacle
Unknown spp.	Unknown ssp.
Juvenile barnacle	Barnacle
Pomatocerous spp.	Tube Worm
Whole dead barnacle	Barnacle
Barnacle Base plate	Barnacle
Bivalve *Anomia* spp.	Bivalve
Bryozoan Encrusting	Bryozoan
Bryozoan erect	Bryozoan
*Diplosoma listeria*num	Ascidian
Tubularia spp.	Hydroid
Other spp.	Hydroid
Sponge sp	Sponge
Didemnid spp.	Ascidian
Blister	Damaged Coating
Bulldozing/cracks	Damaged Coating
Corrosion	Damaged Coating
Bare space	Bare space
Hiatella sp.	Bivalve
Green sp.	Algae
Other spp.	Bivalve
Solitary spp.	Ascidian
Red spp.	Algae
Anemone unknown sp.	Anemone

2.8.2 Statistical analysis

Coating performance data were examined using PRIMER v6. This is a robust and widely applicable statistical tool, used as a standard for multivariate marine community assemblage and biodiversity data, as well as increasingly for commercial environmental assessment data (http://www.primer-e.com/).

The multivariate dataset was fourth root transformed to meet the assumption of equal variance, prior to the creation of Bray-Curtis similarity matrices based on Euclidean distance using 9999 permutations of the residuals under an unrestricted model. For further information on the choice of similarity measures, the numbers of permutations chosen and the level of model restriction used, please see http://www.primer-e.com/.

The Bray-Curtis similarity matrixes were visualised using non metric Multi-Dimensional Scaling (nMDS). nMDS is a convenient way of visualising the relative distance or similarity between samples (coated panels) based on a multivariate data set.

Statistical differences between the samples were tested using ANOSIM in PRIMER v6. R values of 1 indicate significant differences between samples based on the factors: coating names, types and presence of biocidal action.

Where differences between samples were encountered, the SIMPER function in PRIMER v6 was used to identify which variables may have responsible for causing the *dissimilarity* between samples.

NB

Results for this section are not included in this report as they represent commercially sensitive data, therefore cannot be shared with individual manufacturers.

3 Results

3.1 Panel Photographs at 60 months

The abundance of fouling and coating damage was highly variable between coating types. Within each coating type, the position on the pod appeared to influence the amount of fouling present, with substantially less fouling on the lower two rows of the pod, presumably where scouring by mobile sediment had occurred.

Figure 3: Image of whole pod following recovery in 2017 after 60 months *in-situ*.

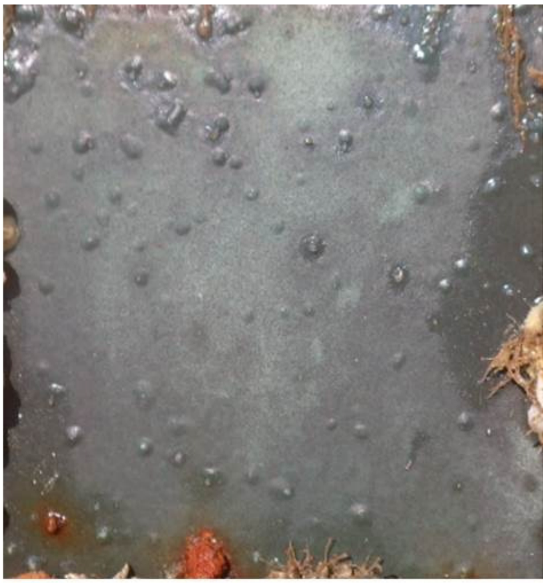

Figure 4: Example of Coppercoat coating following 60 months *in-situ* exposure in a tidal race. All panels are 12x 12 cm^2.

3.2 ROV Survey

3.2.1 Total Fouling

In most cases, the total abundance of fouling decreased over time from 2014, 2015 and 2017, and then usually increased during 2017. The exception in this trend were the "control" coatings – user applied – both of which failed extensively by 2015. By 2015, both of these panel types were essentially unprotected mild steel and covered in severe corrosion. To be noted that Coppercoat's levels of fouling continued to decrease through 2017.

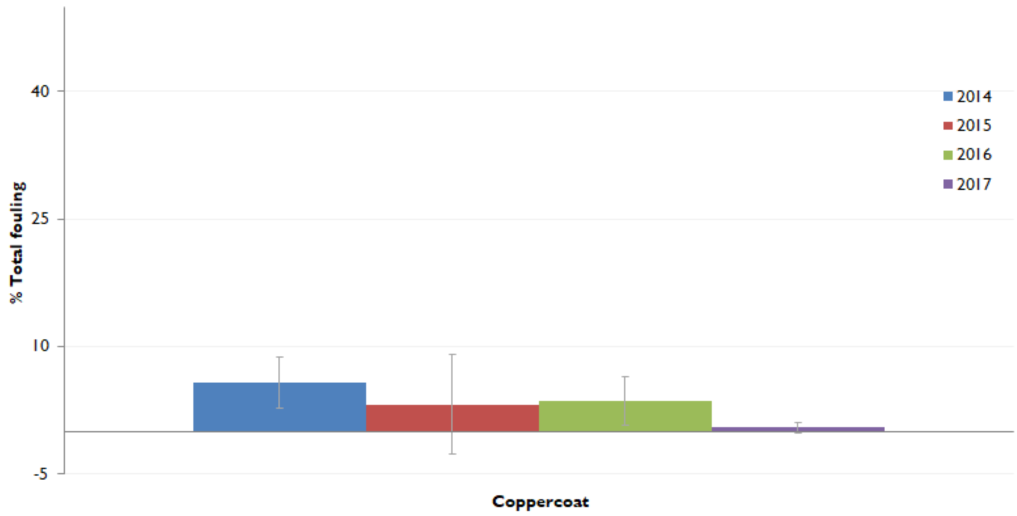

Figure 5: Total percentage cover of fouling from 2014 – 2017 based on ROV data or coarse level image analysis. Error bars indicate standard deviation. n= 10 in 2014, 10 in 2015, 9 in 2016 and 10 in 2017.

Coppercoat was among the top 3 systems with the lowest level of fouling which generally remained at below 10% coverage by fouling between 2014–2017.

3.2.2 Total Damage

Visual damage to Coppercoat panels was not measured for the first 4 years of the project. After post recovery assessment these panels scored total percentage of damage up to 10%.

3.3 Coating Thickness

Coppercoat showed little significant change in thickness over time, excluding inter-panel variability.

Both user applied coating systems had disappeared almost entirely. The remained steel panels had corroded to such an extent that the blistering appeared to show an increase in thickness, but in reality very little if any coating matrix remained in place

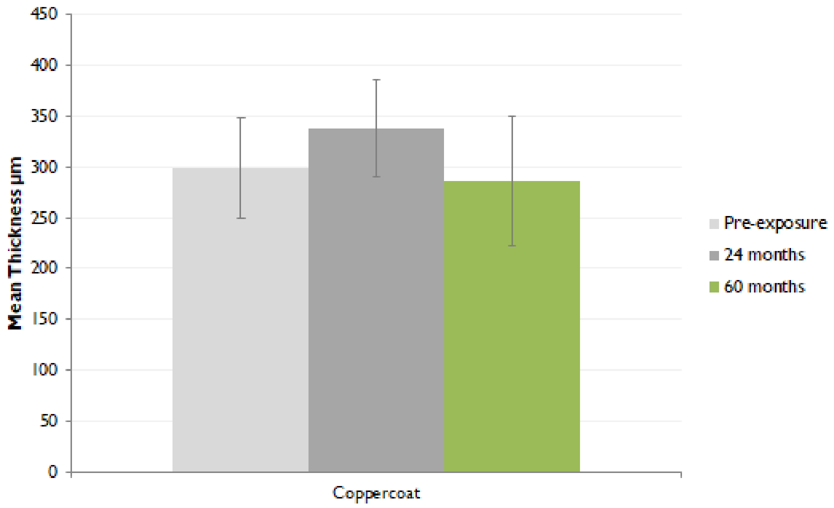

Figure 6: Mean coating thickness pre-exposure, at 24 months and 60 months. Error bars show standard deviation, and n=3.

3.4 Ranking of Performance

Table 4: Ranked order of Coppercoat coating (out of 10) based on their antifouling and damage resistance performance at 24 months. The lowest score indicates the best performance.

Coating Name	Coating Type	Rank (Based on fouling prevention)	Rank (Based on damage prevention)	Score (Fouling + damage)	Rank
Coppercoat	Biocidal Epoxy	3	1	4	2

Table 5: Ranked order of Coppercoat coating (out of 10) based on their antifouling and damage resistance performance at 60 months. The lowest score indicates the best performance.

Coating Name	Coating Type	Rank (Based on fouling prevention)	Rank (Based on damage prevention)	Score (Fouling + damage)	Rank
Coppercoat	Biocidal Epoxy	1	5	6	1

4 Discussion

4.1 Coating Choice

Based on the testing conducted during this study, it is clear that the choice of coating in high energy marine environments, such as tidal streams, can have significant implications for the condition of the underlying structure.

4.2 Value of *in-situ* testing

It is also clear that these comparative field tests provide valuable insight into real word coating performance that can't be gained any other way. To our knowledge, there are no other comparable independent coating efficacy data available at the time of writing that would enable coating selection for temperate tidal streams.

Although the costs associated with testing coatings in this environment are high compared to more benign marine settings, the value of choosing the correct coating system is recuperated very rapidly when maintenance costs arrays of tidal devices is considered.

4.2.1 Natural variation at the test site

This testing also provided important insight in the variability between fouling severity at the test site, together strong evidence of highly destructive scouring events that occur over winter months.

4.3 Key Species

As a result of this work, it is clear that much of the fouling at the site is caused by the occurrence of the acorn barnacle species *Chirona hameri*. The life history of this species is comparatively unstudied, but it is known to be a winter spawner, and is capable of growing to a large size (2cm diameter) in less than 12 months as the test site. This species also appeared to be the cause of the failure of several coating systems, especially the foul release technologies.

The geographic range of the species is not widely known, but in terms of assessing coating performance for tidal streams in Northern Scotland, our study suggests that *Chirona hameri* could be considered a model organism to test antifouling technology against.

4.4 Coating Specification & Strategy

None of the coatings tested here were able to offer full damage resistance and full antifouling protection over the five year test period. In general terms, the protective epoxy based coatings offered superior damage resistance, but failed to prevent fouling. Most of the biocidal antifouling coatings provided a degree of antifouling protection, but the efficacy reduced over time. Where the biocide free foul release coating system remained intact, they offered a good level of biofouling protection. However, where they were subject to mechanical damage, they became readily fouled by multiple cohorts of fouling organisms.

4.5 Coating Longevity

All of the biocidal coatings showed signs of coming to the end of their operational life after 5 years. The user applied SPC had failed soon after 24 months, presumably as a result of poor application procedures. However, the applications instructions from the manufacture were followed as closely as possible, and mimicked how many users will apply coatings i.e. without access to controlled environmental conditions (spray booths) and using rollers rather that spray applicators.

Coppercoat had performed very well for the first four years, but several of the panels began to show signs of blistering and detachment after 5 years. However, where these systems remained intact, they also generally remained effective in preventing fouling.

4.6 Ranking

Based on our section of ranking criteria, Coppercoat was one of the two most successful coatings in terms of preventing fouling and damage at 24 months. After 60 months testing, these two coatings still were in the top two rankings, with Coppercoat on the lead, but were joined by a competitor. However, it is clear that all of these systems were in decline after 5 years. It is expected that they would all lose performance relatively rapidly, as a result of blistering (in Coppercoat), removal of the top coat, and delamination.

It should be noted that our performance criteria omit crucial factors that could prove crucial for developers or utility companies such as initial cost, and environmental biocidal impacts.

4.7 Summary

Not only would the level of fouling measured during this test have the potential to influence the hydrodynamic performance of a device, it would also prevent adequate structural surveys from being undertaken, and could provide a habitat where non-native marine organisms could reside. The latter could provide licencing problems during maintenance events and decommissioning. For these reasons, marine coating selection for assets in tidal streams is a critical.

The information gained during this test provides valuable technology selection support, together with a greater understanding of the environmental challenges at high energy marine sites. Building on this work is very likely to prove cost effective in the medium term, and enable the marine renewable energy aspirations to be realised.

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