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ENDURES- RPT19027

Field efficacy test of antifouling products for pleasure boats in The Netherlands.

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Contents

1 Introduction

On request of the Netherlands Ministry of Infrastructure and Water Endures has carried out a field test into the efficacy of antifouling products for pleasure boats in The Netherlands.
The idea to carry out such field test arose from an antifouling workshop with major stakeholders held in November 2018[1], in which one of the conclusions was that so far there is a lack of reliable data on the effectiveness of alternative antifouling products in practice for pleasure boats. This lack of knowledge forms an obstacle in (public) acceptance of new, more environmentally friendly products.

In consultation with HISWA and the Ministry of Infrastructure and Water a project was defined with a field test on real boats on two locations in the Netherlands. The project was coordinated by HISWA and project funding came from the Ministry of Infrastructure and Water.

Next to the field test on two locations – one location on fresh water (Heeg, Friesland) and one location on salt water (Bruinisse, Zeeland) – the project also contained an additional static exposure test with coated panels at laboratory facilities of Endures in the harbour of Den Helder. Reason for including such raft test is twofold:

- A static exposure test with coated panels is a worst case scenario and will give most demanding conditions for efficacy of antifouling paints;
- Not all (coating) products are tested at both field locations; testing all of them at the same location under the same conditions makes direct comparison of product performance possible.

The products involved in the test were applied on the boats by the suppliers.

For the raft exposure tests antifouling coatings and foil based products needed to be applied onto PVC panels that were provided by Endures. The coated panels were tested in the condition as received.

[1] Innovation Workshop on Safer and Sustainable Antifouling (2018), Rotterdam, The Netherlands.

2 Materials and Methods

2.1 Antifouling products investigated

Suppliers of (alternative) antifouling products were approached by HISWA and asked for possible collaboration in the field test.

Following products were included in the project:

- Melkfett
- Renolit foil
- Avery Dennison foil 1 (AD1)
- Avery Dennison foil 2 (AD2)
- Bioclean (Chugoku Marine Paints)
- Seajet ex3 (Chugoku Marine Paints)
- Silic One (Hempel; one panel blue and one panel red)
- Green Power Nano
- Finsulate (in two versions: short and long fibres)
- Sonihull ultrasound antifouling
- Shipsonic ultrasound antifouling
- Ecospeed

Products were applied onto boats by suppliers according to own specifications. For the raft test Endures provided suppliers with blank PVC panels onto which the coating or foil was applied. The ultrasound systems were only tested on boats at one location (Bruinisse, salt water).

2.2 Raft test in Den Helder

The static exposure test was carried out at the raft of Endures in the harbour of Den Helder (see Figure 1). In this harbour natural tidal currents occur that vary between 0 and 2 knots. Distance from the shore is less than 50 m and water depth at the position of the raft is at least 8 m.

Figure 1. Raft exposure facility of Endures in the harbour of Den Helder, The Netherlands

Panels with coatings and foils were mounted onto one of the exposure racks of the raft facility. In Figure 2 the rack with (almost all) panels is shown prior to immersion. At a later date (July 3, 2019) two more panels with the product

Finsulate were added to this exposure rack. The product Ecospeed was not involved in the raft test.

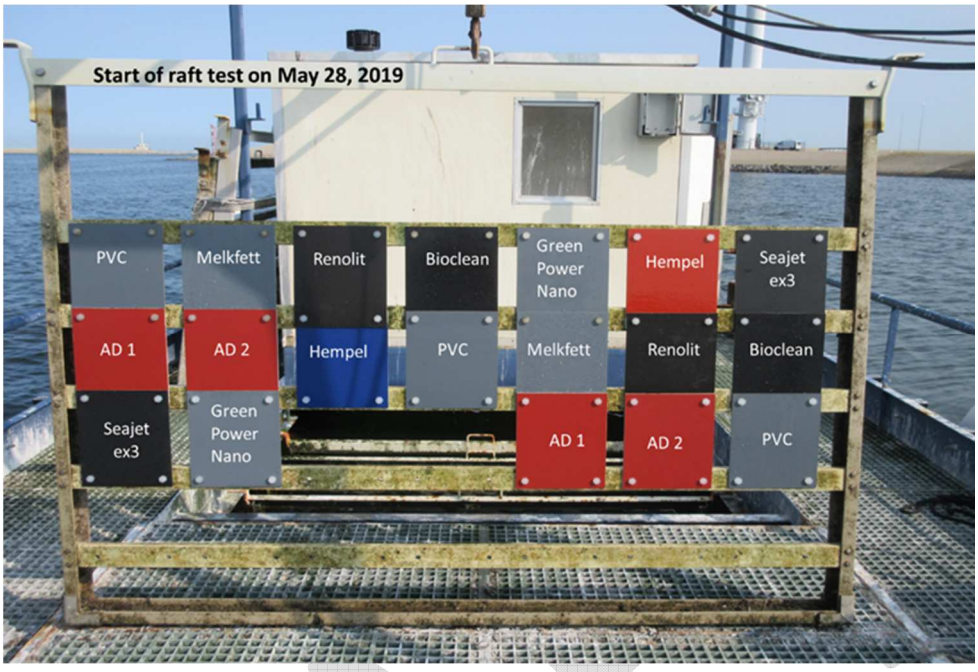


Figure 2. Panels with antifouling products prior to immersion at the raft of Endures.

For each inspection the rack with panels was lifted and fouling that had settled on the frame of the rack and prohibited proper inspection of the panels, was removed. The coated panels were rinsed with seawater to remove silt and non-adhering slime from the surface.
During the inspection estimates were made of the percentage coverage of panels with various groups of fouling organisms. When size and distribution allowed, the exact numbers of macro-fouling organisms attached to the panel were counted as well. Table 1 gives an overview of commonly found groups of fouling organisms in the harbour of Den Helder.

Table 1. Different groups of fouling organisms commonly found in the harbour of Den Helder.

Slime fouling	**S**	Barnacles	**B**
Diatoms (micro-algae)	**D**	young Barnacles	**yB**
Green algae	**GA**	Mussels	**M**
Brown algae	**BA**	Oysters	**O**
Red algae	**RA**	Tunicates	**T**
Sponges	**Spon**	Hydroids	**H**
Tubeworms	**Tube**	Bryozans	**Bryo**

The water conditions in the harbour vary with the season. Main physico-chemical parameters of the seawater are continuously monitored. Figure 3 gives an overview of measurement results (monthly averages) on pH, oxygen content, temperature and salinity during the period January - November 2019.

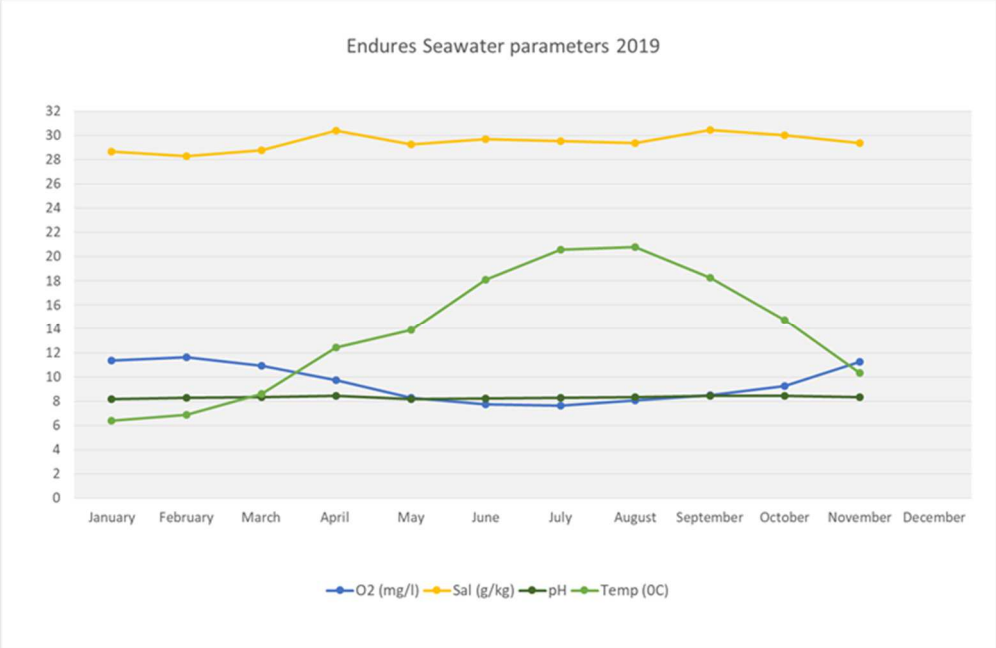


Figure 3. Main physico-chemical parameters of seawater in the harbour of Den Helder in 2019.

2.3 Boat test in Heeg (fresh water)

The field test in fresh water was carried out with boats small boats of the company Ottenhome based in Heeg in the province Friesland. The waters around this location are all fresh water.
The treated boats were polyester boats (type “Valk”) that are used for sailing courses or can be rent for single days up to periods of several weeks.

The company Ottenhome made 7 boats available for this test, these boats were provided with the following products:

- Bioclean
- Seajet ex3
- Melkfett
- Finsulate (short)
- Foil AD2
- Hempel Classic (reference product)
- Boat without antifouling

The reference product (Hempel Classic) is the current standard antifouling paint that Ottenhome applies generally once every two years. The boat without antifouling was included in the test to get a good impression on the fouling condition boats at this location have to deal with.

Ottenhome had a very efficient way of boat lifting for the hull inspections, see the pictures in Figure 4. In this way three inspections were carried out on the following dates: July 4, August 15 and September 24 in 2019.

During the inspections the hull condition of each boat was visually assessed, the type of fouling noted and estimates made of the percentage coverage by various groups of organisms when present. At each inspection photographs were made of the hull and the fouling condition of the boats. Additionally a short summary (in Dutch) was made on the main findings on each boat at each inspection.

Figure 4. Illustration of boat lifting process at fresh water location Ottenhome in Heeg.

Performance evaluation of the various products is based on the findings at the end of the season, therefore the results section of this report will mainly describe the inspection results at the final inspection on September 2019. Where relevant remarks on observations made at earlier inspections will be given as well.

2.4 Boat test in Bruinisse (salt water)

The field test in salt water was carried out with boats owned by the company Aquavitesse based in Bruinisse in the province of Zeeland.
At this location 7 small polyester boats of type “Valk” and 2 polyester sailing yachts of type First were involved in the test.
On the small boats following products were applied:

- Silic One (Hempel)
- Renolit foil
- Seajet ex3 (Chugoku Marine Paints)
- Bioclean (Chugoku Marine Paints)
- Melkfett
- Seajet 023 (reference product; Chugoku Marine Paints)
- Ecospeed[2]

[2] This boat is owned by the company Hydrex NV in Belgium, supplier of Ecospeed.

The two sailing yachts of type First were both provided with an ultrasonic antifouling system; one boat with two transducers made by Sonihull and one boat with one transducer from supplier Shipsonic.
The reference product (Seajet 023) is the current standard antifouling paint that Aquavitesse is using and that is generally applied each year.
At this (salt water) location the fouling pressure is too high to include a boat without antifouling treatment in the test.

Boat lifting procedure at the company Aquavitesse was quite different from the one used in Heeg as illustrated in Figure 5 and Figure 6.
In Bruinisse five inspections were carried out on the following dates: June 13, July 12, August 23, September 19 and October 25 in 2019.

Figure 5. Boat lifting procedure for small boats (“Valken”) at Aquavitesse in Bruinisse.


Figure 6. Boat lifting procedure for larger yachts at Aquavitesse in Bruinisse.

The hulls of the boats with ultrasound devices had been provided in previous years with the reference product. Prior to installation of the transducers the hull was cleaned by high pressure water wash to remove remaining parts of this coating.

Inspection procedure in Bruinisse was similar as described for the fresh water location and also here the performance evaluation of product efficacy was mainly done on basis of observations made at the final inspection on October 25, 2019.
The boat provided with the product Ecospeed was set dry and cleaned outside the water by the owner prior to each inspection.

3 Results

3.1 Inspections raft test

Starting condition of the raft test is shown in Figure 7. Each product is applied on two panels and duplicate panels of products are exposed at different depths.

Figure 7. Panels with antifouling products prior to immersion at the raft of Endures.

3.1.1 First inspection on July 3, 2019

At the time of first inspection two additional PVC panels provided with the product Finsulate (one panel with short fibres and one panel with long fibres; see Figure 8) were mounted on the bottom row of the rack and included in the raft test.

In the overview picture given in Figure 8, it can be seen that most panels only contain slime fouling, except for the panels with products Green Power Nano (GPN) and Seajet ex3. Both panels of these products were largely covered with macro-fouling, *e.g.* barnacles, green and brown algae and colonial tunicates. The pictures in Figure 9 illustrate this with the remark that the Seajet ex3 sample shown here was the panel from the bottom row where algal and slime growth is less prominent and the adult barnacles are clearly visible. Similar numbers of barnacles were also present on the panels with the GPN product.

For comparison the fouling condition of one of the blank PVC panels (top row left) is also shown in Figure 9. Here similar number of adult barnacles are found as on the other two products.
Chugoku as supplier of product Seajet ex3 has further investigated the results of this product and found out that on both panels the topcoat was not the self-polishing coating layer as it should have been. Apparently the wrong topcoat was applied here being the reason for the bad performance of both panels.

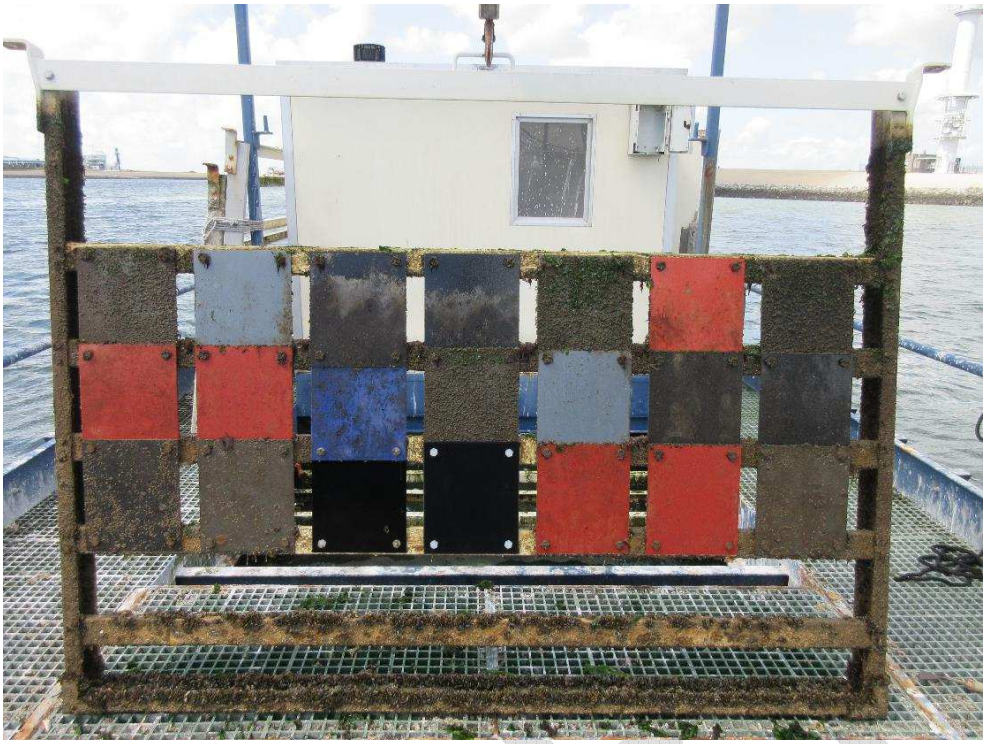


Figure 8. Panels with antifouling products at first inspection on July 3, 2019.

Figure 9. Detailed pictures of panels with Seajet ex3, GPN and blank PVC (from left to right).

3.1.2 Second inspection on July 29, 2019

At the second inspection the difference between effective and non-effective systems is even clearer. Figure 10 gives an overview picture of the condition of all panels.
The panels with non-effective systems are almost fully covered with macro-fouling, next to barnacles and algae also colonial tunicates are now very prominent.

The systems Silic One, Renolit, Bioclean and both types of AD foils, all of these products are based on silicone containing top layers, only have thin slime fouling in variable degree (see Figure 11).
Panels with Melkfett are also almost clean, only small parts of the panel surface were covered with thin slime. On both panels colonial tunicates were found growing around the edge of the panel (see Figure 12). These organisms are

neglected in the evaluation because they have not settled on the Melkfett surface but rather at the untreated back side of the panel.
The panels with Finsulate showed start of growth of mainly colonial tunicates on both the short and long version (Figure 12).

Figure 10. Panels with antifouling products at second inspection on July 29, 2019.

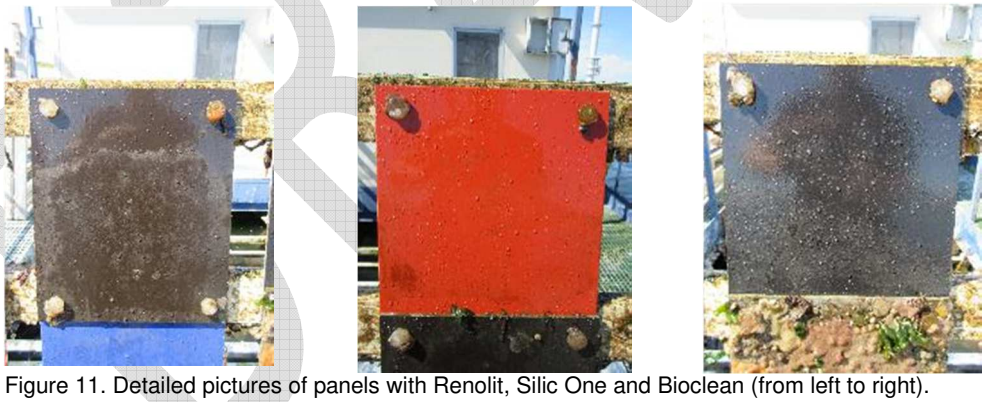


Figure 11. Detailed pictures of panels with Renolit, Silic One and Bioclean (from left to right).

Figure 12. Detailed pictures of panels with Melkfett, Finsulate short and Finsulate long (from left to right).

3.1.3 Third inspection on August 26, 2019

One month later at the next inspection the general picture on panel performance has not changed so much (see Figure 13). Overall the silicone based systems still show good efficacy against macro-fouling although some minor differences are starting to appear. For instance panels with foil AD2 are doing better than panels with foil AD1: on the latter start of growth of some encrusting bryozoans can be seen (see Figure 14).

Figure 13. Panels with antifouling products at third inspection on August 26, 2019.

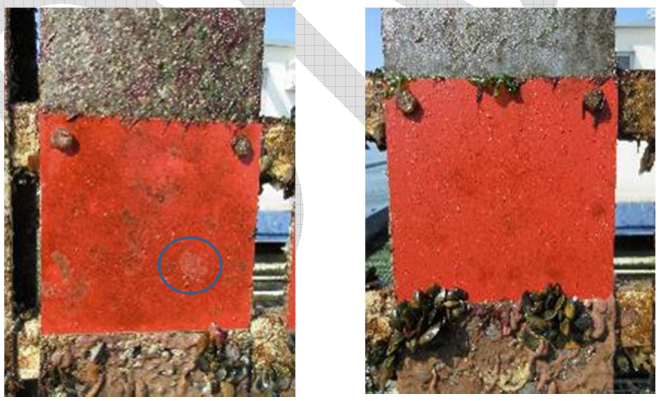


Figure 14. Detailed pictures of panels with foils AD1 (left) and AD2 (right). The blue circle on panel AD1 indicates the location of an encrusting bryozoan.

The top panel with Melkfett shows next to slime fouling also green algal fouling (see Figure 15, right) and the panels with Finsulate are now almost fully covered with colonial tunicates.
One of the Finsulate panels is shown in Figure 15. Striking observation is that underneath the tunicates no barnacles are found in contrast to the fouling observed on panels with non-effective systems and blank PVC where the barnacles are very abundant.


Figure 15. Detailed pictures of panels with Finsulate long (left) and Melkfett (right).

3.1.4 Fourth inspection on September 24, 2019

On September 24, 2019 the final raft inspection was carried out. Figure 16 gives an overview picture of the entire rack with panels. The performance of the separate products is described below and additionally shown in more detailed pictures.

Figure 16. Panels with antifouling products at fourth inspection on September 24, 2019.

The uncoated PVC panels, serving as blanks, were all almost entirely overgrown by diverse macro-fouling such as barnacles, tunicates, green and red algae, mussels and hydroids. Also slime fouling was clearly present on these panels.
Similar fouling patterns were found on panels with products GPN and Seajet ex3.
Clear pictures of such fouling patterns are given in Figure 17 with one panel of each of these products.

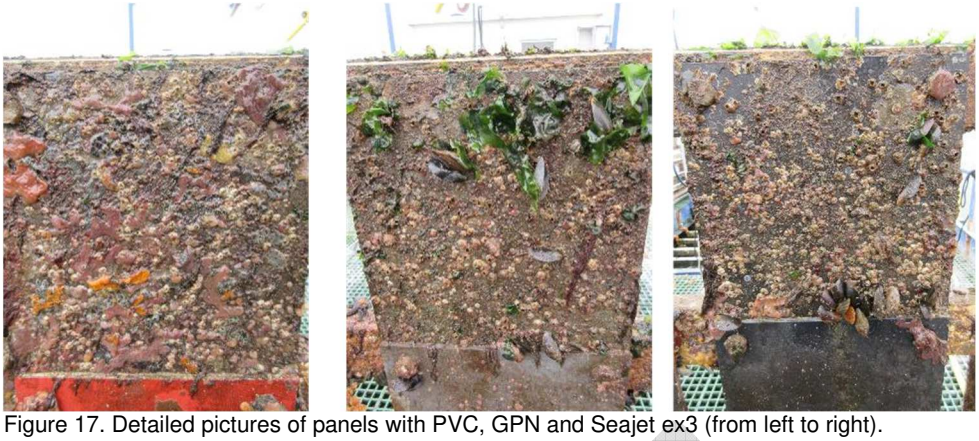


Figure 17. Detailed pictures of panels with PVC, GPN and Seajet ex3 (from left to right).

The panels with Finsulate foils also show substantial coverage with macro-fouling, especially colonial tunicates on 40 - 50 % of the surface and 20 % hydroids. Next to this also single adult tunicates (*Ciona)* were found (see Figure 18).
But an important difference with the PVC and other panels mentioned above is that the Finsulate panels do not contain any barnacles.

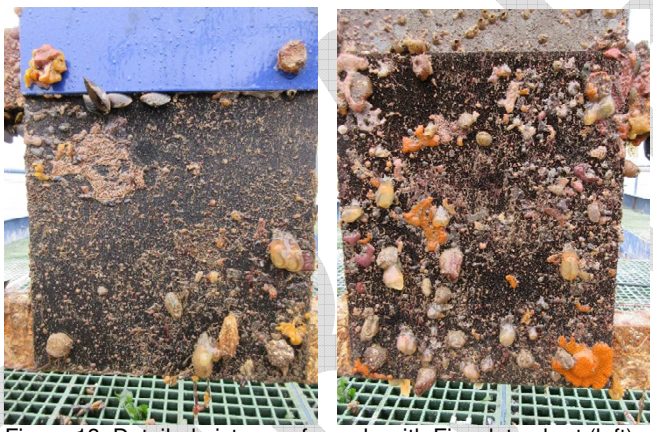


Figure 18. Detailed pictures of panels with Finsulate short (left) and Finsulate long (right).

The panels with AD foils also do not contain adult barnacles and in case of foil type AD2 not even any macro-fouling was found. On foil type AD1 other larger organisms such as (colonial) tunicates, encrusting bryozoans and few hydroids were present, next to slime fouling. The area covered with diatom slime was much larger on foil AD1 than on foil AD2 (see Figure 19). On both types of AD foils no macro-algae have been found during the entire season.

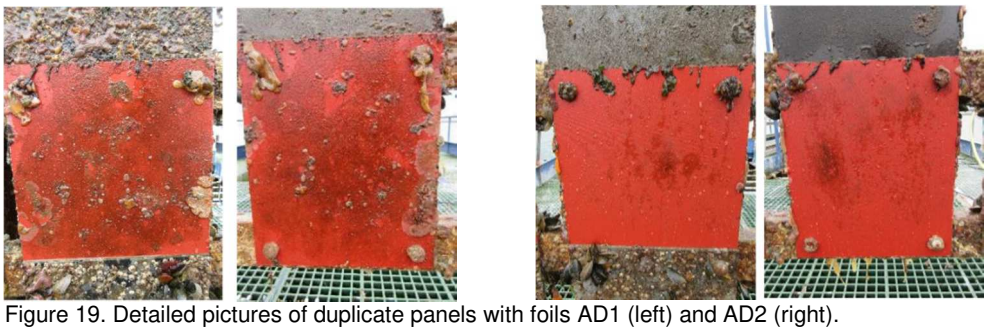


Figure 19. Detailed pictures of duplicate panels with foils AD1 (left) and AD2 (right).

The foil product Renolit shows similar performance as foil AD1 with a number of encrusting bryozoans and small tunicates next to a relatively large area covered with slime (Figure 20).

Performance of Melkfett seems to go down towards the end of the season with increasing numbers of barnacles on both panels, green algae on the top panel and start of colonial tunicates on the lower panel (see Figure 20, far right).

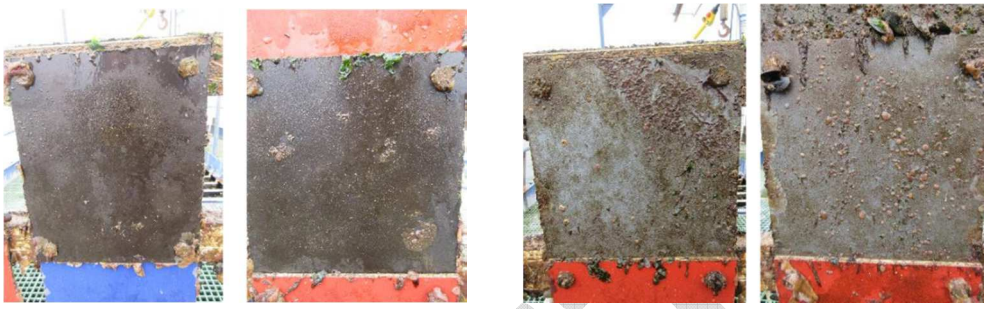


Figure 20. Detailed pictures of duplicate panels with Renolit foil (left) and Melkfett (right).

The panels with silicone based paint systems of Hempel (Silic One) en Chugoku (Bioclean) are shown in Figure 21. On both systems slime fouling was present, on Silic One on a smaller area than on Bioclean, but macro-fouling was not found at the end of the season.
At earlier inspections sometimes very few young barnacles were present but they were never able to stay attached to the coating surface.

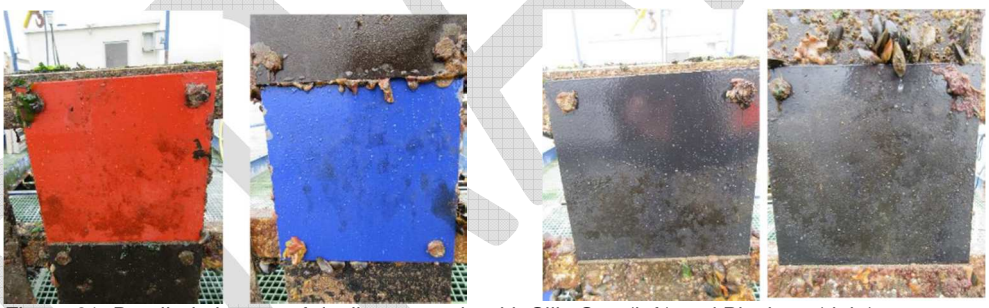


Figure 21. Detailed pictures of duplicate panels with Silic One (left) and Bioclean (right).

3.1.5 Conclusions from the raft test

Conclusions in this section are mainly based on the inspection results of the final inspection on September 24, 2019.

Two paint systems, e.g. Green Power Nano and Seajet ex3 have failed to demonstrate any antifouling effect in this raft test. Investigation by Chugoku revealed that the failure of product Seajet ex3 could be attributed to a mistake made during application of the test panels for this raft test.

The product Finsulate was tested in two versions in the raft test, one panel with short fibres and one panel with long fibres. Both panels showed relatively rapid fouling development during the season with a variety of macro-fouling organisms but dominated by colonial tunicates. In contrast to the blank PVC panels on which high numbers of adult barnacles were found, the panels with Finsulate did not show any barnacle fouling during the entire season.

Up till the second last inspection the product Melkfett showed quite good performance with a small area of green algal fouling and few colonial tunicates. Next to this relatively thick slime was present as well.
At the end of the season one of the panels had a clear increase in barnacle fouling which may indicate that product performance goes down after a couple of months.

Renolit foil has shown significant slime fouling at most inspections and only at the end of the season some macro-fouling developed in the form of encrusting bryozoans.

The Bioclean product also showed significant slime fouling during the season and no macro-fouling until the end of the test when some young barnacles had been able to settle.

Product Silic One from Hempel had relatively small area covered with thin slime and did not show any macro-fouling until the end of the test.

The foil based product AD1 of Avery Dennison showed slime fouling from the beginning and after about 3 months static exposure macro-foulers such as encrusting bryozoans and colonial tunicates had settled.

The foil based product AD2 of Avery Dennison gave better performance than AD1 with little and thin slime fouling only and no macro-fouling during the entire raft test.

<u>Best performing products:</u>

At the end of this test, after 4 months static raft exposure in the harbour of Den Helder, lowest fouling development was observed on the products Silic One from Hempel and foil type AD2 from Avery Dennison.

Table 2 below indicates with different colours the relative performance of products involved in the raft test.

Table 2. Relative efficacy rating of antifouling products after 4 months raft testing in Den Helder.

No efficacy	
Highest efficacy	

PVC		Renolit	
GPN		Avery Dennison 1	
Seajet ex3		Avery Dennison 2	
Finsulate		Silic One	
Melkfett		Bioclean	

3.2 Inspections of boats at fresh water location in Heeg

At the Heeg location three inspections were carried out. A short summary description of inspection results is given in Table 3. Below this table photographs are given with more detailed pictures on the hull condition of boats with the various products at the end of the test.

Table 3. Summary description of inspection results at the fresh water location in Heeg.

	July 4, 2019	August 15, 2019	September 24, 2019
Melkfett	Thin slime at waterline; Patchy distribution of fat	slime fouling; fat layer clearly visible	Hull largely clean; fat has bluish color; no fat at the waterline
Bioclean	local coating detachment; light slime along the waterline	thin slime only; no further detachment; hull largely clean	Hull largely clean; only thin slime along the waterline
Seajet ex3	small blisters in coating; light slime	coating is rough, shows polishing; thick slime on rudder; hull is clean	slime layer at waterline; hull is clean; polishing diminished
Foil AD2	only thin slime; easy to wipe off by hand	thin slime on entire hull; easy to wipe off	slime on entire hull; easy to clean when wet; less easy when dry
Finsulate short	product was not yet applied	hull is clean; short green algae at waterline	at waterline green algae < 1 cm; rest of hull is clean
Reference paint (Hempel Classic)	This boat got paint application in 2018	Hull almost clean; rudder has clear slime fouling	little slime fouling on hull; polished areas at waterline
Gelcoat	These boats were clean at start of season!	thick slime layer on 80 % of hull; difficult to clean by hand	hull fully covered with thick slime; also colonies of algae or hydroids with few small mussels

Melkfett:

The hull of this boat has only limited slime fouling at the waterline; the fatty product shows patchy distribution and partial brownish of bluish discoloration (Figure 22).

Figure 22. Boat with Melkfett product at the final inspection.

Bioclean

Except for thin slime along the waterline, the hull of this boat was largely free from fouling. The right picture in Figure 23 shows a few spots on the hull where the coating had partially detached as reported in the first inspection on July 4, 2019. Nevertheless, no other fouling than slime was present.

Figure 23. Boat with Bioclean product at the final inspection.

Seajet ex3

This (self-polishing) product has kept the hull of the boat almost free from fouling except for some slime patches at the waterline. In the left picture in Figure 24 it can be seen that the coating shows some roughness, probably caused by the small blisters that were detected during the first inspection of this boat.

Figure 24. Boat with Seajet ex3 product at the final inspection.

Foil AD2

Both pictures in Figure 25 clearly show the presence of a slime layer at a large part of the hull. Due to the red colour of the product this dark slime layer obviously can be seen much easier than on the black products on the other boats. As mentioned in Table 3, the slime can easily be wiped off by hand as long as the hull is wet. In dry condition the slime layer is more difficult to remove.

Figure 25. Boat with foil AD2 at the final inspection.

Finsulate (short)

This boat was only inspected twice because at first inspection it was not yet available. Figure 26 shows that the underwater hull of this boat is free from fouling; the only area where fouling is present, is the waterline where relatively short algal filaments were found that had settled between the fibres of the Finsulate product. At the time of inspection the algal threads were shorter than 1 cm but they may grow larger with longer exposure times.

Figure 26. Boat with Finsulate product at the final inspection.

Reference paint

The reference paint used here is the product Classic from Hempel. This is a self-polishing antifouling paint registered for use on pleasure boats. The company Ottenhome knows from experience that this paint works well when applied once every two years. The boats inspected here had been applied in 2018, so the results reported here are not for a freshly applied coating.

The hull condition of these boats (two different boats were inspected on August 15 and September 24) is good; except for some slime patches along the waterline hardly any fouling was present (see Figure 27).

Figure 27. Boat with reference product at the final inspection.

Boat with gelcoat only

The pictures shown in Figure 28 clearly indicate that a boat without antifouling product on the hull suffers from substantial fouling development. At start of the season the boats were clean. In the course of the year a brown and green slime layer builds up to a thickness of one or more millimetres and therein colonies of hydroids or algal organisms may develop. In one such colony a few small fresh water mussels were also found.

From these pictures it can be concluded that doing nothing against fouling at (this) fresh water location is not a good option.

Figure 28. Compilation of pictures of the hull condition of a boat without antifouling at the fresh water location in Heeg.

3.2.1 Conclusions on product efficacy on fresh water

A boat with gelcoat, so without antifouling treatment, is susceptible to significant slime and other fouling. So even on fresh water fouling pressure can be high enough to justify specific measures for fouling control.

On almost all tested systems at this location only slime fouling was found, quite often a little bit thicker around the waterline than on deeper parts of the hull.

On the Finsulate product tested here also short and thin green algal filaments were found at the waterline.

The reference product is still effective in the second year after application.

Product Seajet ex3 shows hardly any fouling during the entire test; at 1st and 2nd inspection this product showed clear polishing behaviour.

The product Melkfett remains present on large part of the hull for the entire season. At the waterline, however, it is mainly gone and there some more slime fouling is usually found.

At first inspection the coating Bioclean showed some local detachment, probably related to an application issue. The product performed well with light slime fouling that could be wiped off easily by hand.

Also foil type AD2 showed only slime forming during the entire season. On a wet surface this slime could be wiped off easily by hand.

Overall conclusion from the field test at this fresh water location is that all products show quite good efficacy. With limited green algae fouling at the waterline the product Finsulate performed slightly less.
Comparative efficacy of the various products is also illustrated in the colour scheme in Table 4 .

Table 4. Relative efficacy rating of antifouling products at the fresh water location in Heeg.

No efficacy	
Highest efficacy	

No antifouling	
Reference (Hempel Classic)	
Avery Dennison 2	
Bioclean	
Seajet ex3	
Finsulate	
Melkfett	

3.3 Inspections of boats at the salt water location in Bruinisse

At the Bruinisse location five inspections were carried out. A short summary description of inspection results is given in Table 5.

Table 5. Summary description of inspection results at the salt water location in Bruinisse.

	June 13, 2019	July 12, 2019	August 23, 2019	September 19, 2019	October 25, 2019
Silic One	young hydroids; large number of small *Spirorbis*	15 % coverage, *Spirorbis,* hydroids, small bryozoans	30 % coverage, *Monia* shells (3-5 cm), hydroids, bryozoans (2-6 cm), 5 % *Spirorbis*	40 % coverage, hydroids, *Spirorbis, Monia,* (4-5 cm), bryozoans, tunicates	35 % coverage, *Monia* shells (3-5 cm), hydroids, sponges, tunicates, bryozoans. No barnacles nor algae
Renolit	small *Spirorbis,* hydroids, bryozoans and tunicates	10 % coverage, *Spirorbis,* hydroids, bryozoans, no barnacles	20 % coverage, *Monia* shells (2-4 cm), bryozoans (3-5 cm), *Spirorbis*	30 % coverage, hydroids, *Monia* shells, *Spirorbis,* and colonial tunicates; no barnacles nor algae	45 % coverage, adult tunicates, bryozoans, new *Spirorbis;* easy clean with water, surface hydrophobic
Seajet ex3	only very thin slime	No fouling	thin brown slime along the waterline; high polishing	hull almost clean; some slime and green algae at waterline	Hull almost clean, thick slime on aft part waterline
Bioclean	Very large number of *Spirorbis,* hydroids, and tunicates. No barnacles	Hull 100 % covered with *Spirorbis,* hydroids, bryozoans and tunicates; no barnacles	Bioclean product removed and replaced by reference paint		
Melkfett	Very large number of *Spirorbis,* hydroids and small tunicates	15 % coverage, especially at waterline, small *Spirorbis,* hydroids, few barnacles	Midship and aft: 20 % coverage with *Spirorbis,* hydroids and bryozoans; fat is coloring blue	Overall 20 % of hull covered; aft part 80 % barnacles and hydroids. At waterline no fat present anymore	Overall 20 % coverage; aft part 70 % barnacles. Midship also small area with barnacles
Reference paint	Very little slime	some slime	Slime fouling, few barnacles (5 mm) and grey hydroid on part of the bow	5 % coverage with barnacles; at waterline 10 %. 40 % coverage thin grey hydroid	75 % of hull thin grey hydroid, Aft part 10 % barnacles, also *Spirorbis* and green algae
Ecospeed + Cleaning	not inspected because product was not yet activated	Hull fully clean	Hull cleaned 2 days before inspection; Remainings of *Spirorbis* and hydroids visible on trailer spot	Hull cleaned 3 days before inspection; fully clean	Hull cleaned 10 days before inspection; fully clean
Shipsonic	hull entirely clean	Almost clean	Thick slime and green algae along waterline; few barnacles	15 % coverage with barnacles, thin grey hydroid on 30 %. Waterline: 30 cm beard of algal fouling. Transducer appeared to be switched off	15 % coverage with barnacles, 50 % of hull thin grey hydroid. At waterline thick slime and green algae (5-10 cm long)
Sonihull	hull almost clean	Almost clean	strong green algae fouling at waterline; small areas with grey hydroid; Strut was broken, boat repaired	Hull almost clean; at waterline dark slime until midship and little algal fouling	At waterline green algae (10-15 cm long) and brown slime. Ca. 10 % thin grey hydroid, no other macrofouling.
Finsulate (2 different yachts)				Product with long fibres applied in May 2019: hull strongly covered with (colonial) tunicates, hydroids and green algae (> 5 cm) at the waterline. Fouling removal relativey easy with spatula.	Product with short fibres applied in 2016: hull strongly covered with tunicates and hydroids; at the waterline green and few red algae. Fouling removal relatively easy with spatula

Further on in this section photographs are given with more detailed pictures of the hull condition of boats with the various products at several inspections.

Hempel Silic One

From the beginning quite strong settlement of young tubeworms (*Spirorbis*) and hydroids. Later on further growth of hydroids, encrusting bryozoans took place and also *Monia* shells with diameter up to 5 cm were found.
Most fouling did not adhere very strong but shells were difficult to remove by hand. At the end of the season approx. 35 % hull coverage with macro-fouling, but neither barnacles nor algae were found on this paint.

August 23, 2019

September 19, 2019

October 25, 2019

Renolit

Early on in the season quite strong settlement of young *Spirorbis*, hydroids and bryozoans. During the season further growth of these groups of organisms and from August onwards also *Monia* shells of 3-5 cm diameter. Except for the shells fouling could easily be removed by hand or water wash. Also on this product neither barnacles nor green algae were found.


August 23, 2019

September 19, 2019


October 25, 2019

Bioclean

This product failed early in the season due to a mistake at application of the paint. After two inspections, the boat owner decided to remove the Bioclean product and replaced it by the reference paint.

June 13, 2019

July 12, 2019

Because of the application failure this boat gave a perfect impression of the strong fouling conditions present at this location early in the season.
From these pictures it is very clear that doing nothing against fouling here, is definitely not an option.

Seajet ex3

The hull of the boat with this product remains free from fouling almost the entire season. Slime fouling was little and very thin until the final inspection in October where some thicker slime was found around the waterline on the aft part of the boat (see picture far right, October 25). This paint has strong polishing properties.


August 23, 2019

September 19, 2019


October 25, 2019

Melkfett

At first inspection large numbers of hydroids, *Spirorbis* and tunicates were found in the fat layer. At second inspection approx. 15 % of hull was covered with hydroids, *Spirorbis* and few barnacles. The fatty product was quite patchy distributed on the hull and showed bluish discoloration. At the end of the season around 20 % of the hull surface covered with macro-fouling, with especially on the aft part barnacles and hydroids op top of this (see picture at the bottom of this page).


July 12, 2019


September 19, 2019

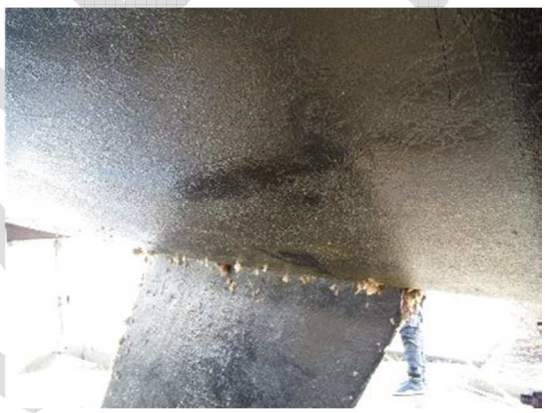


October 25, 2019

Reference paint (Seajet 023)

Only slime fouling in the beginning, later on in the season few barnacles and also grey hydroid were able to settle and grow. At the end of the season around 75 % of the hull was covered with thin grey hydroid (see right picture, October 25).
On the aft part of the boat around 10% was covered with barnacles with hydroids on top of them and here also green algae and some *Spirorbis* were found.

September 19, 2019



October 25, 2019

October 25, 2019

Ecospeed + Cleaning

The boat with this product was inspected four times. Prior to each inspection the boat had been cleaned outside the water by the owner. At each inspection the hull of the boat was perfectly clean but the fouling condition prior to cleaning was never seen.
Picture at the right taken at August 23 shows a small spot were fouling was not fully removed. Here remains' of *Spirorbis* and small hydroids were found.

August 23, 2019

September 19, 2019

October 25, 2019

Shipsonic

In the beginning the hull was entirely clean, about half way of the season some local spots with barnacles and a green algal beard at the waterline (see picture August 23) were found.
Later on (September 19) thick slime fouling was present at the waterline and the transducer was found to be switched off. At the end of the season about 50 % of the underwater hull was covered with thin grey hydroid and local spots of barnacles were found with estimated coverage of 15 %.


August 23, 2019

September 19, 2019



October 25, 2019

Sonihull

In the beginning the hull was entirely clean, later on in August a strong beard of green algae had developed along the waterline. Because of a broken strut that needed repair, the boat stayed out of the water for about a week.
In September dark slime was present and the algal beard was less prominent.
At the end of the season the boat was (still) free from hard fouling but about 10 % of the hull was covered with thin grey hydroid and next to this green algal filaments (10 – 15 cm long) were present at parts along the waterline.

August 23, 2019

September 19, 2019

October 25, 2019

Finsulate

Originally this product was not involved in the test at Bruinisse but thanks to the willingness for collaboration of both the supplier and two private boat owners, two inspections could be done.
Both boats showed severe fouling of mainly (colonial) tunicates and hydroids. Next to this green algae were found along the waterline.
Large part of this fouling could be wiped off relatively easily with a spatula (see pictures of September 19). On both boats no barnacles were found.

September 19, 2019

October 25, 2019

3.3.1 Conclusions on efficacy on salt water

On almost all boats at this location marine fouling was observed, except for the boat with Ecospeed that was only seen after cleaning. Nevertheless, the conclusion is that on all products biofouling was able to settle and grow to more or lesser extent.
The boat initially provided with the product Bioclean, that failed because of an mistake during application, clearly indicates that the fouling pressure at this location is much higher and much more diverse than at the fresh water location.

Comparative efficacy of the various products at this location is illustrated with the colour scheme shown in Table 6.
In principle the efficacy is meant here as the ability of a product to prevent fouling development. This holds for all products except one, the product Ecospeed the performance of which could only be assessed in combination with the cleaning treatment undertaken by Hydrex.

Therefore, in Table 6 the combined performance of Ecospeed + cleaning is shown. In this combination the hull condition of the boat was perfect at each inspection.

The two ultrasonic systems showed slightly different performance with Sonihull (two transducers, one on each side) a little bit better in the second half of the season, but it cannot be excluded that Shipsonic (only 1 transducer) performed less because this transducer was found to be switched off for some time between the third and fourth inspection.
For both systems it can be concluded that they are not able to prevent algal fouling and also slime fouling at the waterline. At the end of the season both ultrasound systems were also not able to keep the hull free from thin hydroid growth.

The Finsulate product showed least performance with regard to prevention of macro-fouling. Especially tunicates and also hydroids were able to colonize the surface quite rapidly. Barnacles were not found on this product.

Table 6. Relative efficacy rating of antifouling products at the salt water location in Bruinisse.

No efficacy	
Highest efficacy	

ShipSonic	
SoniHull	
Renolit	
Silic One	
Reference (Seajet 023)	
Seajet ex3	
Melkfett	
Ecospeed + Cleaning	
Finsulate	

The two (remaining) silicone based products (Renolit foil and Silic One) showed almost similar performance: both were susceptible early in the season to settlement of young *Spirorbis* (small tubeworms) and later on in the season they were not able to prevent settlement of larger organisms such as bryozoans, hydroids and *Monia* shells. On both boats between 35 – 45 % of the hull was covered with such macro-fouling.

The product Melkfett showed on the one hand quite rapidly initial fouling of especially *Spirorbis* and hydroids. From the second inspection onwards, however, the estimated coverage with fouling did not increase very much up to the last two inspections when, on the aft part of the boat, an increasing number of adult barnacles was found. The fat remained clearly visible on a large part of the underwater hull and showed bluish discoloration.

The reference paint Seajet 023 gave a good efficacy up to halfway the season. At the inspections in September and October, however, the performance went down mainly because of increasing growth of thin grey hydroid (same as found on the two yachts with ultrasound) and barnacles that were able to settle on the aft part and at the waterline.

The new product Seajet ex3, also from Chugoku, gave better performance at all inspections. Here only slime fouling was found, in the beginning very thin and slightly thicker at the end of the season.
Apparent aspect of this product was the high polishing rate of the paint which means that the paint layer that was originally applied may decrease more rapidly than that of the reference paint.

4 Environmental aspects of the products tested

4.1 General

In this chapter a concise overview will be given on environmental aspects related to the working principle of specific products during the use phase. Environmental issues related to fabrication, installation or application of products and to the way products should be handled in the waste phase are outside the scope of this project.
For each of the products some remarks are made and two products groups will be discussed in some more detail.

The product Ecospeed is a coating based on vinyl esters reinforced with glass platelets. The coating forms an impermeable barrier layer for water, does not contain any biocide and is VOC compliant. The coating itself does not prevent fouling settlement and growth but in combination with cleaning the product is advertised as a solution to fouling problems. After curing the product does not release any chemical and the coating is very hard and resistant to all sorts of cleaning treatments. In this project the boat with Ecospeed was cleaned outside the water prior to every inspection. In a study by Wijga *et al.* (2008)[3] cleaning tests were done in which it was found that particles entering the environment were mainly of biological origin (remains of fouling) and that the product was environmentally safe.

The product Finsulate is described as a fouling resistant wrap that is applied onto boats using an adhesive layer. The product looks like a soft carpet and contains small nylon fibres that make the surface unattractive for settlement of different types of fouling organisms. The system consists of three layers: a pressure sensitive adhesive based on modified acrylic, a polyester film and as topcoat a cured acrylic adhesive with nylon fibres embedded. The product does not release any chemical during the use phase. It is clear from the field test that fouling is not prevented on this product. With hardly any hard fouling present on the surface, cleaning can be done relatively easily. One aspect that might need some (further) attention is possible loss of nylon fibres due to ageing, wear off or repeated cleaning of the product.

Melkfett is a fatty product mainly consisting of aliphatic hydrocarbons such as Vaseline and/or paraffin. It forms a thick fatty layer when applied onto the hull of a boat. After first immersion of a treated boat, the water surrounding the boat also carries a thin oily layer for a couple of days. The fat remains present on the hull of the boat for a couple of months, albeit more patchy towards the end of the season.
Working principle most likely is that fouling organisms do not like or cannot deal with the gel like layer at the surface that they do not (directly) recognize as a suitable surface for settlement. In this way it works on a physical basis.
The environmental consequences of release of fatty or oily components right after immersion of a treated boat have not been studied yet but may need some further attention.

The working principle of ultrasonic systems for fouling control is still unclear, nevertheless they work otherwise suppliers would not claim that they have sold thousands of systems worldwide for various applications. One application that is known for quite some time already is the control of algal fouling in (fish) ponds. Striking observation in this project is that with both systems tested the efficacy against green algae is not very high considering the fact that on both boats during the season quite strong algal growth was observed along the waterline.

[3] Wijga *et al.*(2008). Biocidevrije 'antifouling' voor schepen. Emissies vanuit de onderwatercoating 'Ecospeed'. Rijkswaterstaat Report nr. 2008.057.

But against other types of marine fouling the systems do work and obviously we are talking about a physical principle here that does not fall under the biocidal product regulation. The sound waves generated by the transducers travel first through the hull material and from there can be radiated into the surrounding water. Once in the water sound waves can travel significant distances (> 100 m) but sound intensity will diminish very rapidly with the distance. Transducers of different suppliers may generate different types of ultrasound bursts, in frequencies as well as over time. From environmental point of view it could be relevant to have a more detailed look into the distribution of sound in a marina with multiple boats using ultrasonic systems and possible consequences for underwater life.

4.2 Products based on silicones

The active principle of a silicone based fouling release coating is based on a surface with physical properties that make it difficult for fouling organisms to settle and adhere. In case organisms do settle on such surface they are usually easy to remove either by water flow when a boat is sailing or by cleaning. This physical principle will work as long as the coating surface stays intact. Without damage the effective lifetime of a silicone based coating can reach 10 years or more. But when the surface gets damaged the anti-settlement properties will diminish and fouling organisms may find such places and start to grow.

For products based on silicone binders an important aspect is the fact that in several of these products organotin based catalysts (mainly dibutyltin-laureate, DBT) are used for curing of the topcoat. The catalyst is required to get proper film formation of the coating and thereby an effective product with the right surface properties. The amount of catalyst in the paint formulation is very low percentage wise and in case of DBT there is IMO regulation in place that limits its content to a maximum of 0.25 % (w/w) in the paint. A catalyst is generally not consumed in the chemical process which means that after curing of the paint DBT will stay inside the coating layer. Shortly after curing it might be possible that some unused catalyst material is present on the surface of the topcoat. Upon first immersion of the coating the catalyst molecules may diffuse or dissolve into the water but only for a short period and with the limit mentioned above in mind, only in very low concentration.

To put this aspect in the right perspective it is important to realize that in the past, when organotin based paints were still allowed to be used, all registered paints contained Tributyltin (TBT) instead of DBT (because TBT was a far more effective biocide) and that the TBT content in paints could range between 10 and 30 % (Ytreberg *et al*. 2016)[4].
With regard to leaching of catalyst components some papers were found in the literature. Karlsson & Eklund (2004)[5] reported on toxicity tests with leachate water from various paints and they found no toxic effects on red algae and copepod larvae in water samples of the silicone based product Intersleek 700.

In Watermann *et al*. (2005)[6], scrapings from 10 different silicone based coatings were investigated on DBT content. In 6 out of the 10 products minute amounts of DBT were found whereas the other 4 products did not contain any organotin. In parallel to this analysis, leachate water samples were collected from all 10 coatings and used in toxicity tests with barnacle larvae and luminescent bacteria. All products tested did not show toxic effects on barnacle larvae nor on

[4] Ytreberg *et al*. (2016). XRF measurements of tin, copper and zinc in antifouling paints coated on leisure boats. Environmental Pollution 213: 594-599.
[5] Karlsson J & Eklund B. (2004). New biocide-free antifouling paints are toxic. Marine Pollution Bulletin 49: 456-464.
[6] Watermann *et al*. (2005). Bioassays and selected chemical analysis of biocide-free antifouling coatings. Chemosphere 60: 1530-1541.

the bacteria. Overall conclusion of these authors was that the silicone based products investigated did not display toxic properties.

But DBT is not the only catalyst for curing silicone based paints, other chemicals can be used as well.

In this field test 5 different products on silicone basis have been tested, 3 different foil types and 2 different paints. The paint products Bioclean and Silic One do not contain a tin based catalyst.
The silicone top layers of the foil based products of Avery Dennison and Renolit are prepared using a tin based catalyst but all products fully comply with IMO regulations.

Another aspect that is relevant here is the fact that (at least in the past) a number of silicone based paints contain silicone oils that may leach from the coating during part of its lifetime. Main purpose of adding these oils is to make the surface even more slippery and thereby enhance the non-stick properties of the coating. Locally such oils may spread as a thin, non-biodegradable film over the water surface which could give problems for gill breathing organisms although such effects have not been reported in literature.

Silicone based coatings do not polish or otherwise decrease in thickness over time. These coatings may have much longer lifetimes than self-polishing coatings as long as the topcoat remains intact. Upon damage the coating may give off small or larger particles of binder material. The degradation process of the polydimethylsiloxane (PDMS) binder of silicone based paints is mainly abiotic: Graiver et al. (2003)[7] report that in sediment depolymerisation of PDMS into smaller oligomers can take place. In a paper by Nendza (2007)[8] it is reported that PDMS particles do not bio-accumulate but they can be persistent and may absorb to other particles in the water or in sediment.

4.3 Eroding / self-polishing paints

The polishing behaviour of antifouling paints can be seen as a more or less controlled dissolution of the paint layer during its lifetime. The term erodible paint is commonly used for paints based on resins such as rosin, a natural compound obtained from pine trees whereas the term self-polishing paints is used for products based on more advanced binders (acrylates) with adjustable polishing properties. Playing around with hydrophilic and hydrophobic substitutes in the basic binder molecule may give products with high or low polishing rates suitable for specific sailing conditions.

Almost all self-polishing paints contain biocides that are toxic to major groups of fouling organisms. Best known biocide in this respect is of course copper or cuprous oxide, a compound highly effective against hard animal fouling such as barnacles and tubeworms. Next to copper another biocide can be added for instance against other fouling organisms such as green algae (seaweed).
The polishing behaviour of antifouling paints results in continuous renewal of the coating surface and with this also leaching of the biocide(s) is more or less controlled. At certain point, depending on polishing rate and on initial layer thickness applied, the paint will become ineffective when most of it is polished away. At that time the boat needs to be provided with a new coat.

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[7] Graiver *et al.* (2003). A review of fate and effects of silicones in the environment. J. Polym. Environ. 11 (4): 129-136.

[8] Nendza (2007). Hazard assessment of silicone oils used in antifouling-/foul-release-products in the marine environment. Marine Pollution Bulletin 54: 1190-1196.

Zinc oxide is a commonly used compound in erodible or self-polishing paints. The compound is not added for its biocidal effects, although on some organisms it may have toxic effects, but rather for enhancing the polishing behaviour of paints and to increase the efficacy of copper (Lagerström *et al*. 2018)[9].

The reference products used on the boats in Heeg (Hempel Classic) and Bruinisse (Seajet 023) both belong to the category of erodible paints. They are based on rosin binder material and contain 10.1 and 12.2 % copper, respectively.

The product Seajet ex3 is a new product of Chugoku Marine Paint that is currently in the registration process for approval under the BPR. This paint contains no copper but another biocide that is approved for use as an active ingredient in PT21 products, *e.g.* antifouling paints.
Reason for including this product in the field test is to see how this copper free product compares in performance to existing biocidal paints that all contain between 8 and 12 % copper. This experimental product is also a self-polishing paint with an acrylate binder system that showed relatively strong polishing. The product also contains zinc oxide.

[9] Lagerström *et al*. (2018). In situ release rates of Cu and Zn from commercial antifouling paints at different salinities. Marine Pollution Bulletin 127: 289-296.

5 Conclusions

For each of the three test locations conclusions are drawn on product performance to prevent or reduce fouling settlement and growth.

Raft test

Ten products compared in an exposure period of 4 months during which 4 inspections were carried out to establish antifouling performance.

1. Best performing products were foil based product AD2 (Avery Dennison) with silicone top layer and the silicone based paint Silic One (Hempel) that both showed only thin slime and no macro-fouling during the entire exposure period.

2. Other silicone based products (Renolit, AD1, Bioclean) and the product Melkfett gave slightly less performance with higher rates of macro-fouling especially at 3rd and 4th inspection.

3. Product Finsulate showed quite rapid development of soft animal fouling but barnacles were not found.

Field test at fresh water

Six products compared on boats exposed for 6 months at fresh water location in Heeg, Friesland; 3 inspections carried out.

4. All products tested at this location performed equally well; mainly slime fouling was observed except on product Finsulate where at the waterline also small filaments of green algae were found.

5. Boats without antifouling treatment suffer from severe slime fouling building up to a layer of 1 mm or more in which also small mussels and colonial forms of other fouling organisms may establish.

Field test at salt water

Ten products compared on boats exposed for 6 months at salt water location in Bruinisse, Zeeland; 5 inspections carried out.

6. Product (combination) that was best able to provide a boat hull free from marine fouling was the coating Ecospeed + cleaning. At all inspections the hull of this boat was perfectly clean.

7. Best performing product with regard to fouling prevention was the coating Seajet ex3 with only slime fouling during the entire season. An apparent property of this paint was the strong polishing behaviour.

8. Of the two ultrasound systems Sonihull showed a slightly better performance with less barnacle fouling than Shipsonic. The latter system was found to be switched off for some time during the season, this could explain its lower performance at later inspections.

9. Ultrasound systems cannot prevent fouling of (green) algae along the waterline.

10. Melkfett shows rapid initial fouling with different types of young organisms but large part of them are not able to settle permanently. Later on in the season the aft part of the boat got an increasing number of barnacles.

11. The silicone based products Silic One (Hempel) and Renolit foil showed more or less similar performance with around 40% of the hull covered with macro-fouling at the end of the season. Except for shells, most fouling could easily be washed off. On both products barnacles nor green algae were found.

12. Boats provided with the Finsulate product showed large areas of the hull covered with high numbers of (colonial) tunicates and hydroids. Along the waterline green algae and slime were found. Using a spatula, this fouling can be removed relatively easily.

6 Signature

Den Helder, January 16, 2020 ENDURES B.V.

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