Corrosion behaviour of copper alloys
in natural sea water and polluted sea water

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ABSTRACT

Copper based alloys are frequently used in marine water systems. They have indeed an attractive price and offer interesting mechanical characteristics associated to a relatively good resistance to corrosion in sea water. Nevertheless, they can suffer from certain forms of corrosion such as localised corrosion with sulphides pollution, crevice corrosion, or stress corrosion cracking in sea water more or less polluted with ammonia.

A high strength copper nickel alloy (Nibron) and a Nickel Aluminium Bronze (A45) are respectively compared to classical CuNi 90-10 (CuNi10Fe1Mn) and CuAl9Ni3Fe2, elsewhere well known for their experimental feedback in sea water.

Standard electrochemical tests such as polarization resistance, open circuit potential measurements and polarization curves are implemented in natural sea water and polluted sea water. Static and under fretting crevice corrosion tests as well as specific stress corrosion cracking tests with ammonia pollution are also conducted.

The copper alloys compared have shown rather similar behaviour in sea water. In near stagnant conditions, risk of corrosion initiation in sea water is high with these alloys (localised corrosion, crevice corrosion close to the gasket, corrosion under deposit, stress corrosion cracking).

Usual recommendations for the use of copper alloys in sea water (ie passivation in clean sea water, suitable range of flow rate, biocide treatment) must be strictly followed in order to limit localised corrosion.

KEYWORDS: corrosion tests, copper alloys, natural sea water, polluted sea water

INTRODUCTION

Copper based alloys are frequently used in sea water system for applications such as heat exchangers, pumps, valves, pipes, fasteners. Depending on the applications and the need for mechanical characteristics, CuNi alloys (ie CuNi10Fe1Mn) or Nickel Aluminium Bronzes can be used. Despite the emergence in recent years of other materials that offer improved properties such as stainless steels, based nickel alloys or titanium, copper alloys continue to be widely used. They have indeed an attractive price and offer interesting mechanical characteristics associated to a relatively good resistance to corrosion in sea water. Nevertheless, they can suffer from certain forms of corrosion such as localised corrosion with sulphides pollution [1-6], crevice corrosion in valves or flanges assemblies [7-9]. Some cases of stress corrosion cracking in sea water more or less polluted with ammonia were also reported [10-12].

This paper summarises the results of a comparative test campaign conducted in natural sea water and polluted sea water on a high strength copper nickel alloy (Nibron compared to the classical CuNi10Fe1Mn) and a Nickel Aluminium Bronzes (A45 compared to CuAl9Ni3Fe2). Nibron and A45 being dedicated for fastener applications.

The following classical electrochemical tests were first conducted in natural sea water to assess corrosion parameters in the absence of critical interface:
-Open circuit potential (Eoc) and polarization resistance (Rp)
-Anodic polarization curves
-Weight loss measurements and corrosion rates estimation.
Secondly, the influence of sulphide or ammonia pollutions was investigated through the same approach.
Thirdly, critical interface that simulated flanges assemblies were considered and tested through crevice corrosion potentiostatic tests with a potential imposed close to Eoc.
Then, as relative micro displacements could be generated in certain assemblies, comparative tests regarding crevice corrosion initiation under fretting were also carried out.
Finally, as NAB could be susceptible to Stress Corrosion Cracking (SCC) in natural sea water or polluted sea water with ammonia, SCC U-bend tests were conducted.

EXPERIMENTAL PROCEDURE

<u>Materials</u>

Nominal compositions and mechanical properties of the base materials used are found in tables 1 and 2 with reference to certificate data, but also to analysis and mechanical tests conducted by the CESMAN[1] depending on the material considered.

<u>Specimens conditioning</u>

All specimens used were wet polished to a final finish with 600-grade SiC paper except SCC specimens that were polished to a 240-grit finish, degreased in methanol, rinsed in deionised water and then air dried. Prior to testing, all specimens were immersed in circulating natural sea water (2l/min) during about one month. Sea water is pumped from Cherbourg harbour with the temperature varying from 17°C to 20°C during the period of tests.

[1]CESMAN Centre d'Expertises des Structures et MAtériaux Navals (de DCNS)

Corrosion testing

Eoc and Rp measurements
Eoc and Rp measurements were conducted on specimens machined from bars with a flag shape to enable electric connection out of them sea water, the dimensions being of 25 mm in length and 25 mm in width. Eoc was measured with respect to Saturated Calomel reference Electrode (SCE). Rp measurements were obtained with linear polarization data acquired using a potentiostat by imposing a small amplitude potential of 15 mV around Eoc. The sweep rate was 0.05 mV/s. Rp was taken as the slope of the I= f(E) curve near Eoc. Triplicate specimens were weighted before immersion and after cleaning with descaling solvents. Comparisons were made in each case with control specimens. Weight loss measurements were used to estimate the corrosion rates in μm/year. Specimen examination was conducted before and after cleaning. Tests were conducted in natural sea water during about 3 months but also in polluted sea water with sulphides or ammonia. Sea water pollution was simulated through Na_2S addition of 10 ppm S^{2-}, in quiescent sea water (Contact time 30 min before recirculation) every day during 5 days. The results obtained in non polluted circulating sea water were compared to those in polluted sea water after about 3 months of test. Ammonia additions were considered as another possible pollution that can be encountered in stagnant conditions due to organic matter degradation. NH_4OH was then added to stagnant sea water up to 1700 ppm of NH_3, renewed every 2 weeks during more than one month. The results obtained in stagnant sea water renewed every 2 weeks were compared to those in stagnant sea water polluted with ammonia.

Polarization curves
The anodic polarization curves were generated using a potentiostat, at a scan rate of 0.05 mV/s, from Eoc to 0.3 V vs. SCE. The tests were conducted on "flag specimen" of 25 mm in length and 25 mm in width. Conditions of tests were the same as those selected for Eoc measurements.

Static crevice corrosion tests
The crevice device, shown in fig 1, was used in order to simulate metal /gasket interfaces such as flanges assembly under static conditions. The gaskets were aramid fiber gaskets and the assemblies were tightened to a controlled torque of 25 N.m leading to a pressure about 20 N/mm^2. It was lower than in service pressure but considered as a significant condition. One of the metallic surface was enlarged to enable crevice initiation out of the interface as it was generally observed in service. Potentiostatic tests, at ambient temperature, were conducted during 73 days in circulating natural sea water under an imposed potential chosen close to the Eoc measured.

Crevice corrosion tests under fretting
Assemblies used for crevice corrosion testing assisted by fretting consisted of three specimens with cylindrical bosses fastened through their central hole with a controlled pressure of 2 N/mm^2 as shown in figure 2. The tests were performed in natural sea water at a controlled temperature of 25°C. Micro–displacements of 10 microns were generated at a frequency of 10 Hz for 2 or 3 hours. Potentiostatic tests were conducted increasing the potential step by step. The first phase consist of waiting for steady current close to Eoc potential, then implementing a fretting sequence and recording the corresponding current. Then, potential was increased and the fretting sequence implemented. This step was repeated until the current reached 10^{-4} to 10^{-3} Amps.

<u>Stress corrosion cracking tests</u>
U-Bend tests were conducted according to ISO 7539-3 standard (ref 13).Tests parameters were selected with regard to those defined previously to estimate CuAl9Ni3Fe2 SCC susceptibility in natural sea water and polluted stagnant sea water with aqueous ammonia [14]. Specimens were bent to a bending radius of 14 mm. Test environments chosen were natural sea water and stagnant sea water added with two concentrations of aqueous ammonia: 170 ppm (0.01 mol/l) and 1700 ppm(0.1 mol/l). Cracks were indeed observed on CuAl9Ni3Fe2 in these conditions after respectively 1000 h and 120 h of test duration(ref 14). Each specimen was duplicated and two test durations were selected, 1000 hours and 5000 hours (four specimens tested in each condition).

RESULTS AND DISCUSSION

<u>Corrosion parameters in natural sea water (absence of critical interface)</u>

Eoc measurements of Nibron compared to CuNi10Fe1Mn are given in Figure 3. In natural sea water, Nibron Eoc is maintained around -250 mV vs. SCE over a period of time of about one month. Then, Eoc increases to -70 mV vs. SCE after 2 months of test. The triplicate specimens in test give the same results.
Rp measurements of Nibron , shown in Figure 4, confirms this tendency to corrosion initiation with an initial value of 5000 to 10 000 Ohm decreasing to between 10 and 300 Ohm after 2 months of exposure to sea water. Nibron specimens examinations, presented in Figure 5, shows green oxidation products significant of corrosion initiation. The mean corrosion rate is nevertheless low around 18 μm/year. Pitting corrosion is observed but the pit depths are too low to be estimated. After one month of exposure to natural sea water, anodic polarization curves, in Figure 6, exhibit no actual passivation threshold, the current density increases from 10^{-7} A/cm^2 to about 10^{-5} A/cm^2 up to a potential of -50 mV vs. SCE. Over this potential, anodic current sharply increases to 10^{-3} A/cm^2. If Nibron is compared to the classical CuNi10Fe1Mn, mean corrosion rate could be considered similar respectively 18 μm/year and 15 μm/year but Nibron could have a higher tendency to pitting in natural sea water. Eoc and Rp measurements confirm this different behaviour. CuNi10Fe1Mn presents indeed a steady potential and Rp with time, respectively -200 mV vs. SCE and 2000 Ohm as Nibron shows an increase in potential over -100 mV vs. SCE and a decrease in Rp under 100 Ohm after 2 months of exposure to sea water.

In conclusion, Nibron could be considered a bit more susceptible to corrosion and especially localised corrosion than CuNi10Fe1Mn in natural sea water.

Eoc measurements of A45 compared to the NAB CuAl9Ni3Fe2 are given in Figure 7. Similar phenomenon is observed on both alloys, that is an increase in potential from -250 mV vs. SCE to -90 mV vs. SCE after 2 months of exposure to sea water. At the same time, Rp shown in Figure 8, presents similar evolution with a decrease from a steady value of 3000 Ohm to 100 Ohm after 2 months of test. Specimen examinations reveal a mean corrosion rate of 37 μm/year with a localised corrosion observed near the coated electric connection evaluated at 1.3 mm/year, the max. depth being of about 150 to 300 μm. Similar observations are made on CuAl9Ni3Fe2. Anodic polarization curves performed on A45 and CuAl9Ni3Fe2 , in Figures 9 and 10, are very similar. No actual passivation thresholds are observed in both cases. For A45, current densities increase slowly from 10^{-6} A/cm^2 to 10^{-5}

A/cm^2 between -220 mV vs. SCE and -100 mV vs. SCE. Then, over – 100 mV vs. SCE , current densities sharply increase to 10^{-3} A/cm^2.

In conclusion, electrochemical behaviour of A45 and CuAl9Ni3Fe2 are very similar with a higher tendency to localised corrosion of these both alloys compared to Nibron or CuNi10Fe1Mn.

Influence of sulphides pollution on corrosion parameters

With suphides pollution, Eoc measured on Nibron shown in Figure 3 increases from - 250 mV vs. SCE to -70 mV vs SCE after 2 months of test, as it was observed in natural sea water. At the same time Rp , in Figure 4, decreases to 100 Ohm. Specimen examination after the test, reveals an important green oxides deposit as shown in Figure 5 with a mean corrosion rate estimated about 49 μm/year. Nibron anodic polarization curve with sulphides pollution is very similar to those of CuNi10Fe1Mn. Anodic current, in Figure 6, sharply increases to 10^{-4} A/cm^2 for a potential between -100 mV vs. SCE and -30 mVvs.SCE.

In conclusion, with sulphides pollution, Nibron presents a comparative behaviour to CuNi10Fe1Mn. Compared to results in natural sea water, mean corrosion rates are increased and affected areas are spread all over the exposed surface in both cases.

Influence of ammonia pollution on corrosion parameters

With ammonia pollution, A45 Eoc, shown in Figure 11, decreases from – 250 mV vs ECS to -350 mV vs. ECS. This decrease in potential was checked on Pt Electrode. The same phenomenon is also observed on CuAl9Ni3Fe2 (see Figure 12). Specimen examinations after the tests reveal a superficial corrosion with no significant pitting. The mean corrosion rates for A45 and CuAl9Ni3Fe2 are respectively 13 μm/year and 16 mm/year. Anodic polarization curves performed on A45 and CuAl9Ni3Fe2, in Figure 9 and 10 reveal a significant increase in current between -150 mV vs. SCE and – 250 mV vs. SCE in sea water with ammonia pollution. The current densities reach 7.10^{-5} A/cm^2.

In conclusion, these tests reveal the potential risk of galvanic coupling between a surface polluted with ammonia and a large surface in unpolluted natural sea water.

Parameters of crevice corrosion initiation (Static tests) in natural sea water

Tests conducted on Nibron, under – 70 mV vs ECS in Figure 13, lead to a high current around 10^{-3} A/cm^2 after 100 hours of test. A uniform corrosion is observed, localised out of the crevice interface. CuNi10Fe1Mn presents exactly the same phenomenon with lower current about 5. 10^{-5} A/cm^2 under a potential of -75 mV vs.ECS.

On A45, the current measured under – 100 mV vs SCE is 10^{-5} A/cm^2 after 100 hours of test. Then, it increases gradually to 10^{-4} A/cm^2 (see Figure 14). Corrosion is observed out of the crevice interface but localised at the edge of the gasket. A45 and CuAl9Ni3Fe2 show a very similar behaviour.

In conclusion, the various materials tested show a certain susceptibility to crevice corrosion. In each case, this corrosion is localised out of the crevice interface and close to the gasket edge in the case of NAB.

Parameters of crevice corrosion initiation and propagation under fretting in natural sea water

On the Nibron crevice device, tests begin under a potential of -150 mVvs.SCE. As shown in Figure 15, currents are maintained low (10^{-6} A) for a potential varying from – 150 mV vs SCE to -100 mV vs SCE. Above these potential, currents become significant from -70 mV vs SCE and reach 8. 10^{-4}A. Fretting induces no significant increase in current. For imposed potentials from -60 mV vs. SCE to -50 mV vs. SCE, corrosion currents are very high (2.10^{-3}A). After the tests, specimen examination, presented in Figure 16, reveals superficial corroded areas at the periphery and corrosion initiates near the hole but this corrosion has occurred during the initial immersion phase but not during the fretting step.

A comparative test conducted on CuNi10Fe1Mn with the results shown on Figure 17 and 18 leads to the same conclusions with no significant effect of the fretting observed. Initiation potential is estimated around -70 mV vs. SCE under static conditions as under fretting. Corrosion areas are also mainly located at the periphery of the specimen.

On A45 (see Figure 19), corrosion initiates naturally under free potential (-105 mV vs. SCE) at the beginning of the test. Under – 100 mV vs. SCE, the current reaches 2. 10^{-4} A which is higher than those observed on Nibron and CuNi10Fe1Mn in the same conditions. Under -80 mV vs. SCE, fretting has got an effect on the current measured: after a fretting step of about one hour, corrosion current increases from 4.410^{-4} A to 6.2 10^{-4} A. From – 70 mVvs SCE, the current measured become very high (10^{-3} A) but similar under static conditions and under fretting. Specimen examination, shown on Figure 20, reveals after the fretting test a selective corrosion at the periphery of the specimen with dealuminisation, the maximum corrosion depth being of 0.1 mm.

The comparative test conducted on CuAl9Ni3Fe2,in Figures 21 and 22, leads to similar observations with lower currents measured. Under -100 mV vs. SCE, the current measured is indeed 9 fold higher on A45. In both cases, A45 and CuAl9Ni3Fe2, fretting begins to be effective from -80 mV vs SCE with high steady currents that reached respectively 6.2 10^{-4} A and 2.8 10^{-3}A. The crevice corrosion test under static conditions previously presented, seems to be less severe with corrosion current measured around 10^{-4} A under a potential of – 100 mV vs.SCE.

In conclusion, initiation potentials in static conditions and under fretting are similar but fretting could have an effect on corrosion rates especially on A45 and CuAl9Ni3Fe2. Globally corrosion initiated naturally during the immersion phase and propagated under imposed potential essentially out of the crevice interface under fretting but also in static conditions.

U-bend SCC tests in natural sea water and polluted sea water with ammonia

On A45, cracks initiate in sea water polluted with 1700 ppm of ammonia after 1000 hours of tests as shown in Figures 23 and 24, but not in natural sea water and polluted sea water with 170 ppm of ammonia. By comparison, CuAl9Ni3Fe2, suffers from SCC in natural sea water and polluted sea water with only 170 ppm of ammonia. Experimental feedback presented previously [14] had confirmed the susceptibility CuAl9Ni3Fe2 in stagnant sea water in long term service conditions. The test in sea water polluted with ammonia was considered as one possible simulation of SCC phenomenon in stagnant sea water. In that conditions, A45 could be considered as susceptible to SCC in stagnant sea water but high concentrations of ammonia are needed to reveal its susceptibility compared to CuAl9Ni3Fe2 so that it appears less critical.

U-bend tests conducted on Nibron compared to CuNi10Fe1Mn, shown in Figures 25 and 26 has revealed no susceptibility of both alloys to SCC in natural sea water but also in stagnant sea water possibly polluted with ammonia after 5000 hours of tests.

CONCLUSION

A comparative test campaign was conducted in natural sea water and polluted sea water on a high strength copper nickel alloy (Nibron compared to the classical CuNi10Fe1Mn) and a Nickel Aluminium Bronzes (A45 compared to CuAl9Ni3Fe2). The following conclusions can be drawn from this study:

1. In natural sea water Nibron appears slightly more susceptible to corrosion than CuNi10Fe1Mn, A45 and CuAl9Ni3Fe2 have a similar behaviour considering electrochemical tests.
2. Sulphides pollution leads to a significant increase in corrosion on Nibron and CuNi10Fe1Mn.
3. NH_3 pollution increases the risk of SCC on A45 and CuAl9Ni3Fe2 as Nibron and CuNi10Fe1Mn show no susceptibility to this form of corrosion.
4. Presence of gasket increases the risk of crevice corrosion initiation near the gasket but not under the gasket, phenomenon more over observed in operating conditions.
5. Crevice corrosion initiation potentials are similar under static conditions and under fretting. For A45 and CuAl9Ni3Fe2, fretting could have an effect on corrosion rates, currents level are higher. Globally, corrosion can initiate naturally during the immersion phase in sea water and propagate under imposed potential essentially outside interface specially under fretting conditions but also in static conditions.

Globally, the copper alloys compared have shown rather similar behaviour. In sea water near stagnant conditions, risk of corrosion initiation is high with these alloys (localised corrosion, crevice corrosion close to the gasket, corrosion under deposit, stress corrosion cracking). Usual recommendations for the use of copper alloys in sea water (ie passivation in clean sea water, suitable range of flow rate, biocide treatment) must be strictly followed in order to limit localised corrosion.

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Material	Al	Zn	Ni	Fe	Mn	Impur	Si	Sn+Pb	P	C	S	Cu
Nibron According to CESMAN analysis	2.53	0.006	13.8	1.06	0.43		0.004	0.0010 (Pb)	<0.003	0.004	<0.001	82
CuNi10Fe1Mn Certificate data		0.006	10.5	1.7	0.87	0.04		0.004	0.015	0.009	0.005	Bal
A45 Certificate data	9.96	0.01	4.80	3.28	0.55	0.04	Nil	0.15 (Sn)				Bal (incl Ag)
CuAl9Ni3Fe2 Certificate data	8.8	0.01	2.7	2.1	1.37	0.04	0.03	0.02 (Sn) 0.001 (Pb)				Bal

Table 1: Chemical composition of the base metal alloys (% in weight)

Material	0.2% YS (MPa)	UTS (MPa)	Elongation %	Hardness Average value
CuNi10Fe1Mn Certificate data	129	320	42.6	90 (HB)
Nibron according to CESMAN tests	579	811	17.5	
CuAl9Ni3Fe2 Certificate data	251	576	54	137(HB)
A45 According to CESMAN tests	640	810	20	

Table 2: Mechanical properties of the base metal alloys

Diamètre 3 mm

Diamètre 36 mm

Diamètre 10 mm

2 mm

50 mm

5 mm

Titanium bolt and screw

Aramid fiber gasket

diameter 30 mm washer

Titanium plate

•*polished to a 600-grit finish*
•*Controlled pressure 20 N/mm²*
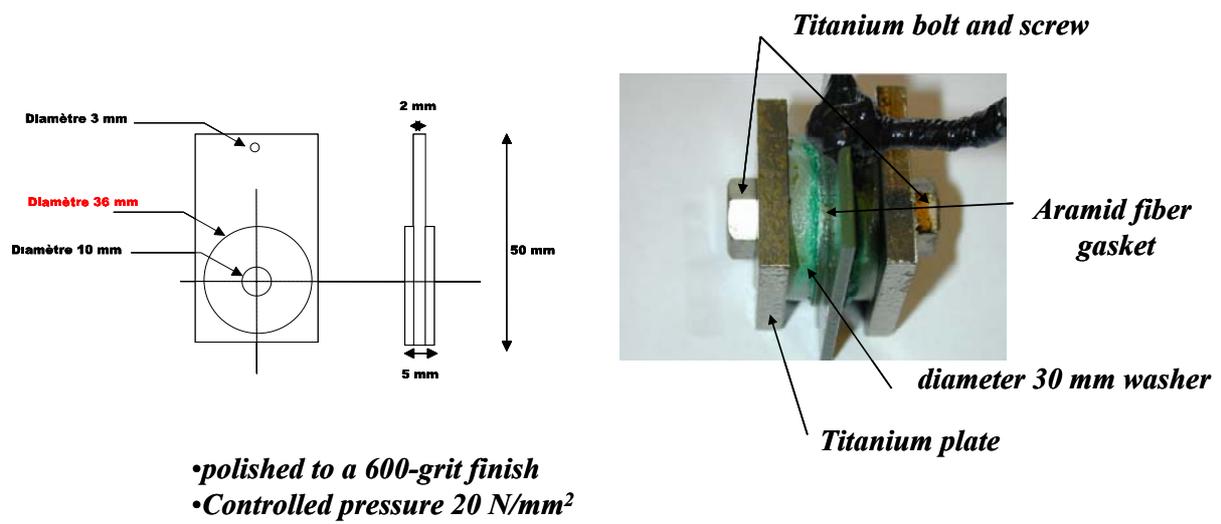
Figure 1 : Static crevice test device

Corrosion current monitoring

Displacement Generator

Potentiostat

Potential monitoring
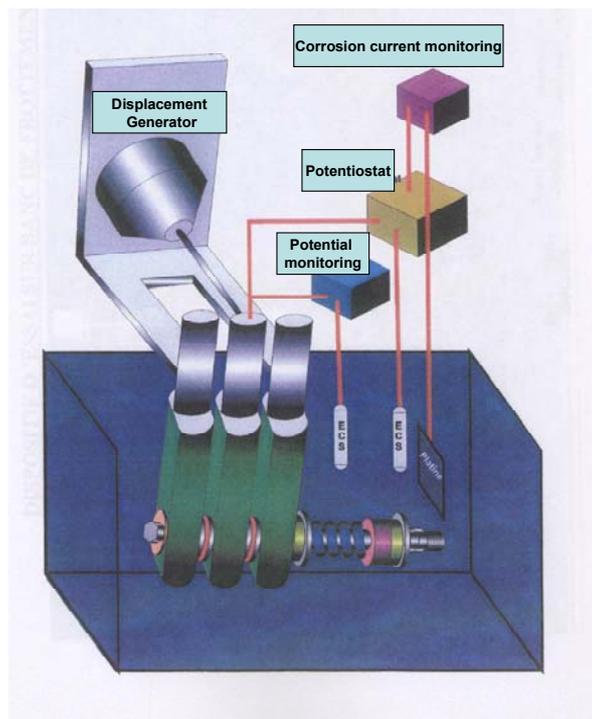
Figure 2 : Crevice Corrosion test bench under fretting
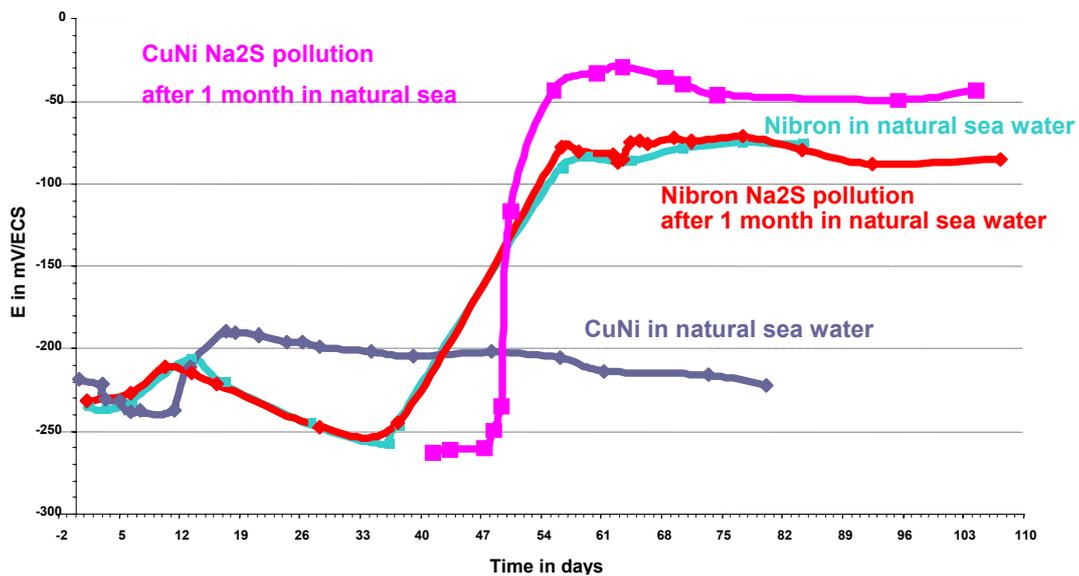
Figure 3 : *Eoc in natural sea water and polluted sea water with sulphides*
Comparison between Nibron and CuNi10Fe1Mn
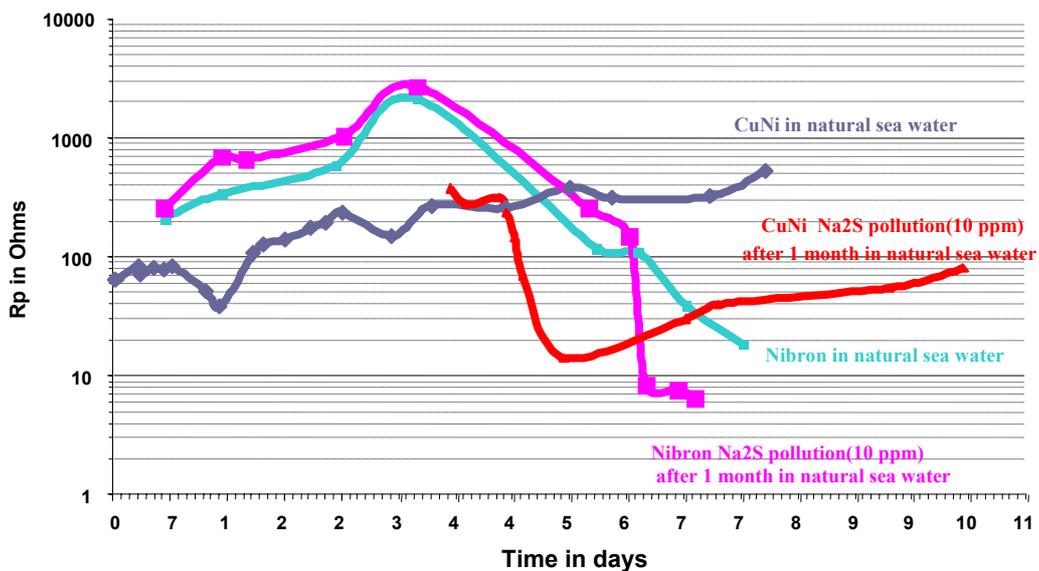
Figure4 : *Rp in natural sea water and polluted sea water with sulphides*
Comparison between Nibron and CuNi10Fe1Mn

Nibron test in natural sea water sea water
Mean corrosion rate = 18µm/year.

Nibron Na2S pollution
Mean corrosion rate = 49µm/year.

CuNi90-10 test in natural sea water
.
Mean corrosion rate = 15µm/year.

CuNi90-10 Na2S pollution.

Mean corrosion rate = 52µm/year.
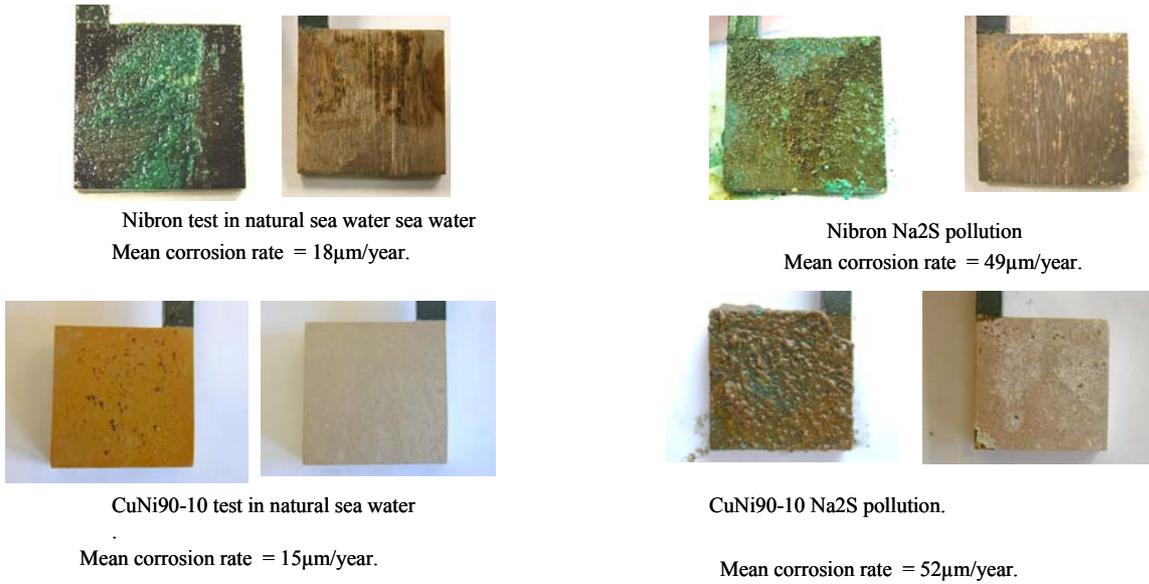
Figure 5 : *Specimen examination after exposure to natural sea water and polluted sea water with sulphides*
Comparison between Nibron and CuNi10Fe1Mn
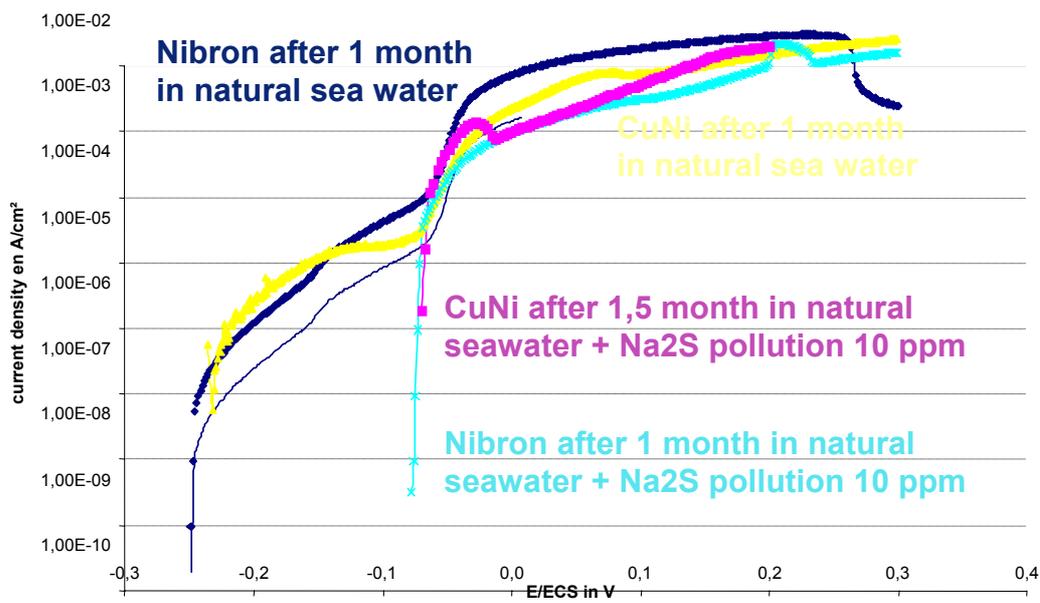
Figure 6: Anodic polarization curves after exposure to natural sea water and polluted sea water with sulphides
Comparison between Nibron and CuNi10Fe1Mn
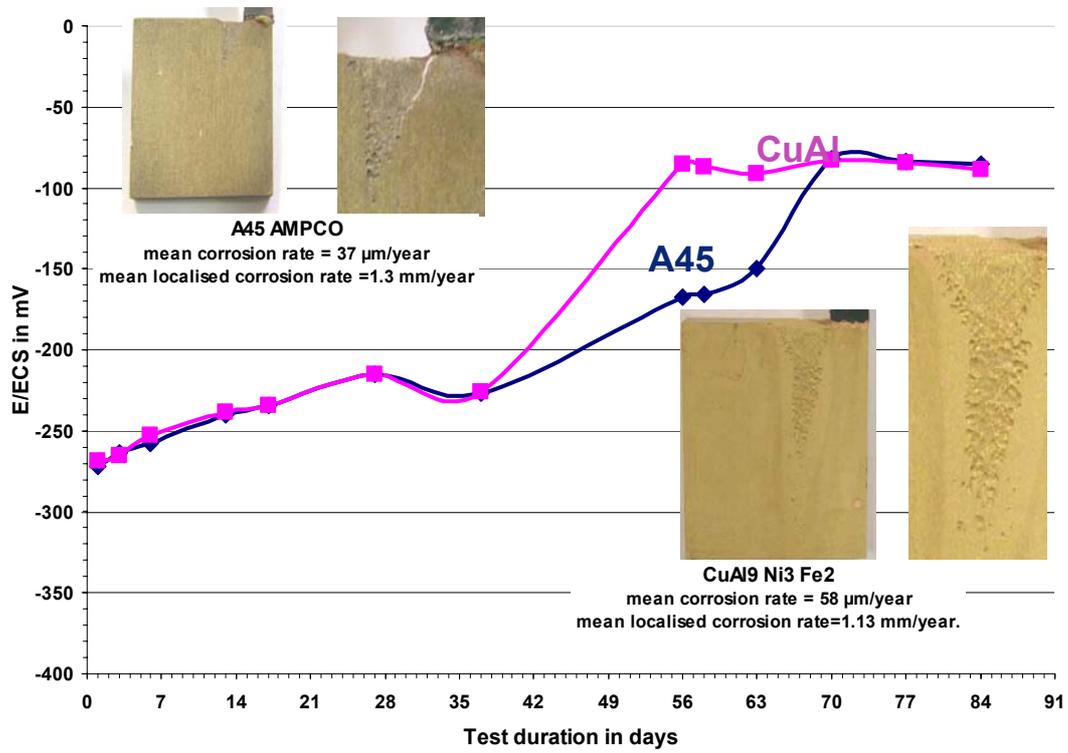
Figure 7: Eoc in natural sea water
Comparison between A45 and CuAl9Ni3Fe2
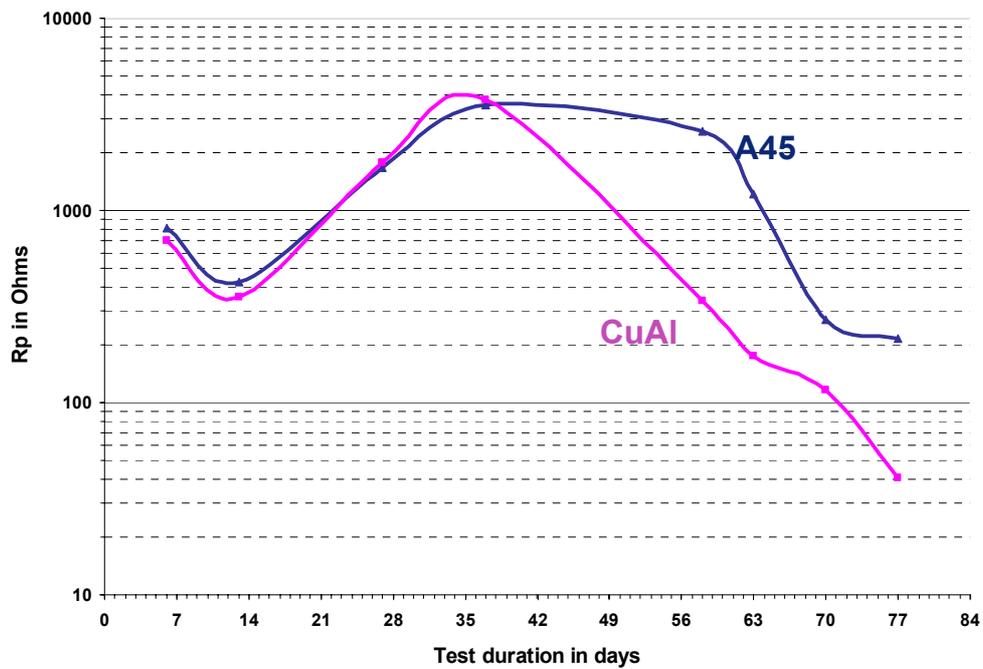
Figure 8: Rp in natural sea water-Comparison between A45 and CuAl9Ni3Fe2

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A45 - natural seawater + NH3 pollution (1700 ppm) at ambient temperature

- A45 one month in circulating natural seawater *(reference)*

- **A45 one month in circulating natural seawater then seawater treated with NH3 (1700 ppm)**

- **A45 one month and 3 weeks in circulating seawater then tseawater teated with NH3 (1700ppm)**

Legend: 459, 455, 4523

Scanning rate 0.05 mV/s
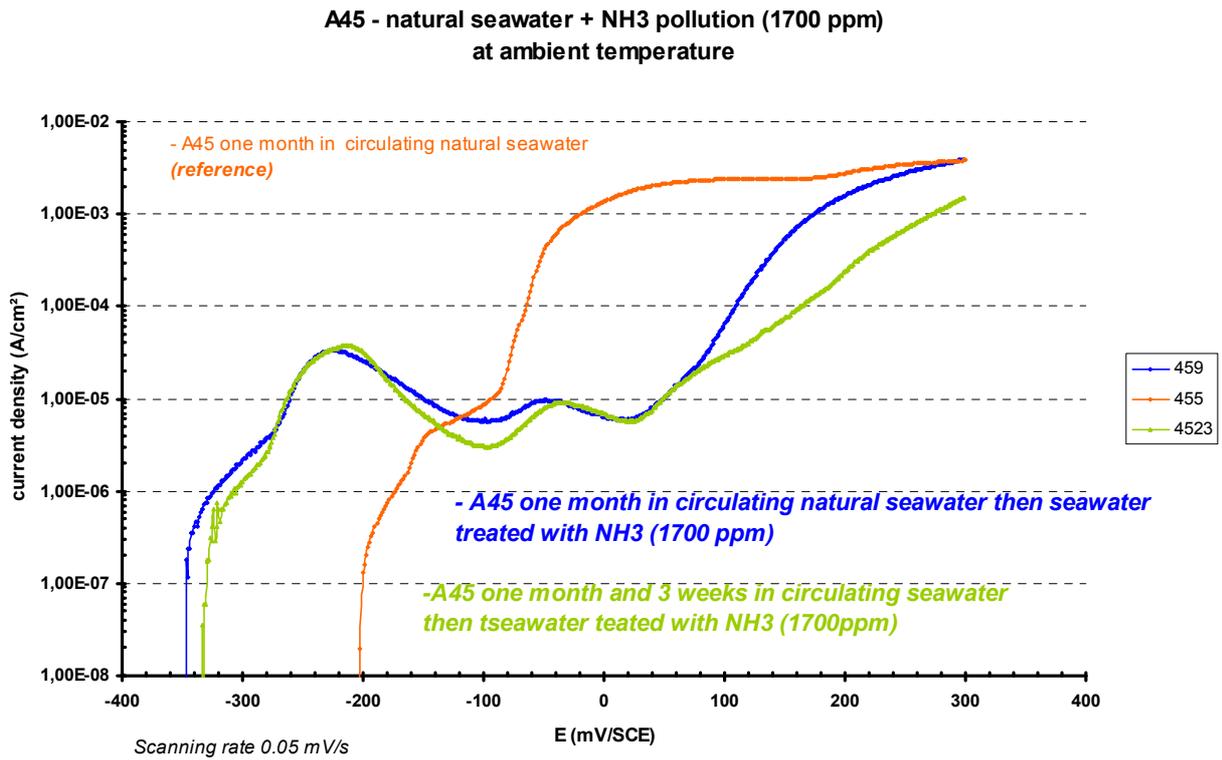
Figure 9: A45 Anodic polarization curves after exposure to natural sea water and polluted sea water with ammonia

CuAl9Ni3Fe2 - Natural seawater + NH3 pollution (1700 ppm) at 20°C

Natural seawater

C23 in natural seawater one month before NH3 treatment (1700 ppm)

C25 in natural seawater one month and a half before NH3 treatment (1700 ppm)

Legend: C23, C6, C25

scanning rate 0.05 mV/s
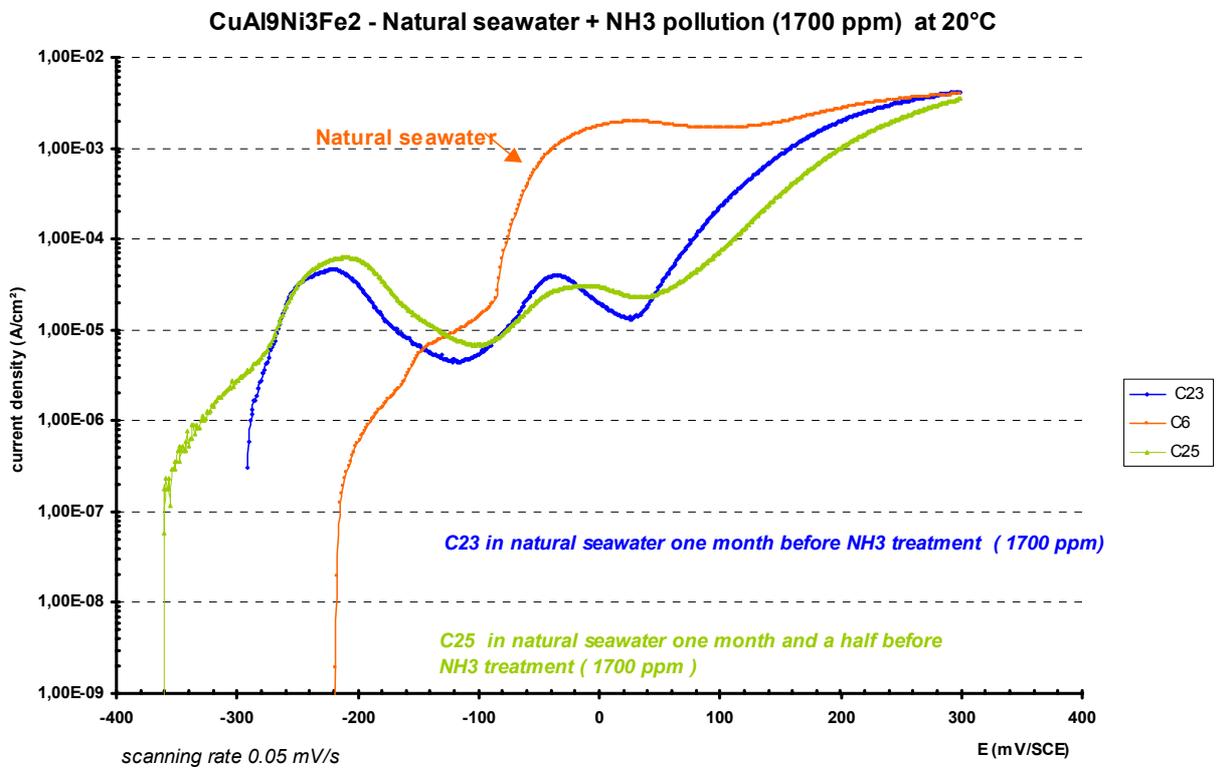
Figure 10: CuAl9Ni3Fe2

Anodic polarization curves after exposure to natural sea water and polluted sea water with ammonia

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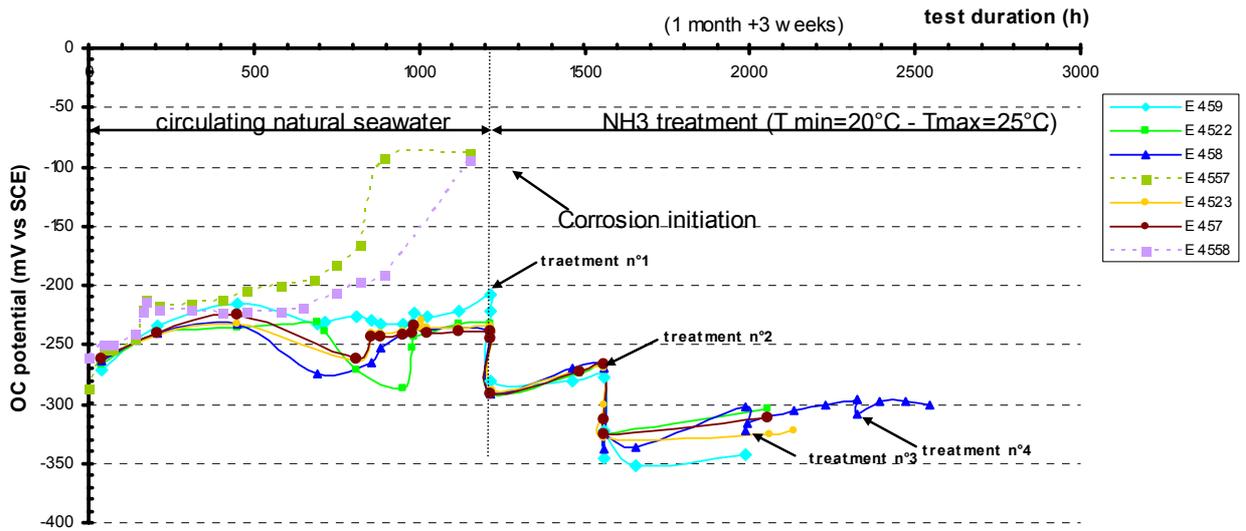
Figure 11: A45 Eoc in natural sea water and polluted sea water with ammonia
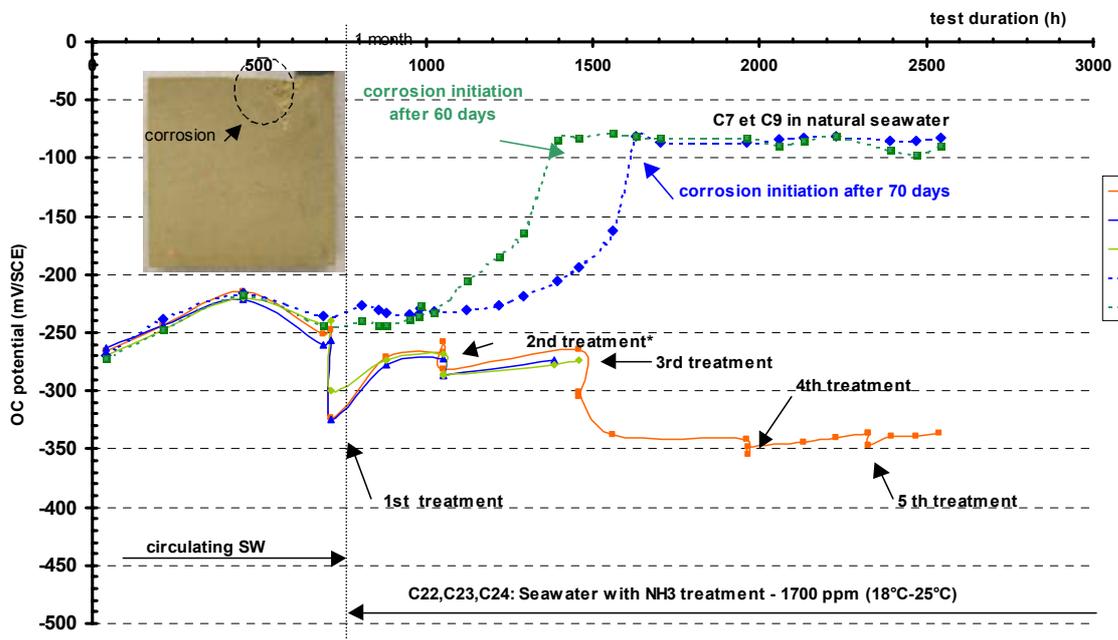
Figure 12: CuAl9Ni3Fe2
Eoc in natural sea water and polluted sea water with ammonia
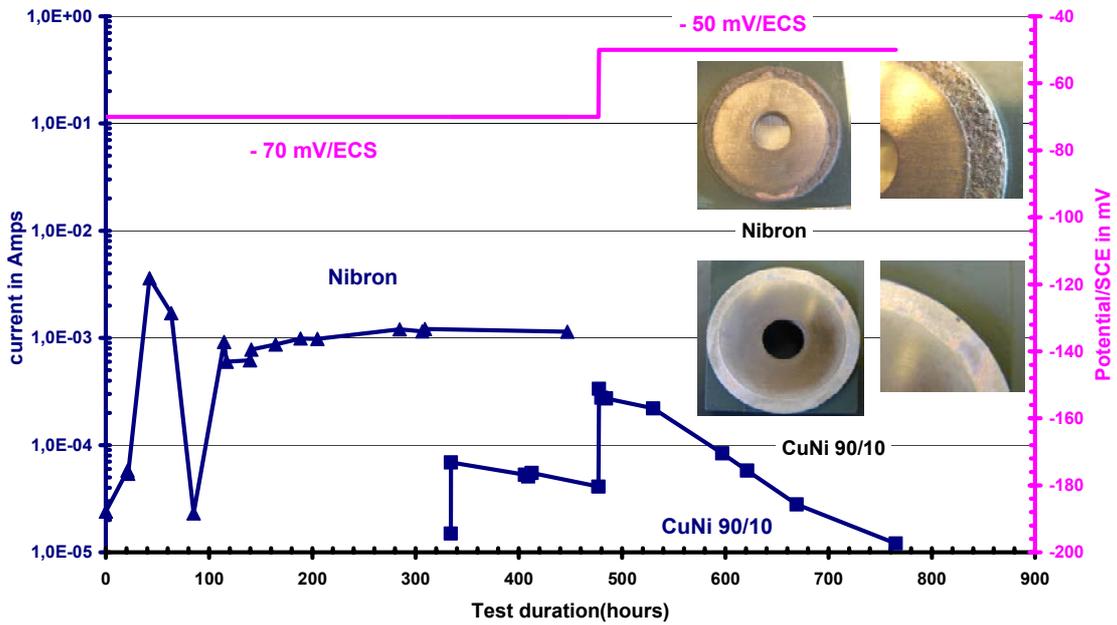
Figure 13
Crevice corrosion initiation in natural sea water (ambient temperature)
Comparison between Nibron and CuNi10Fe1Mn
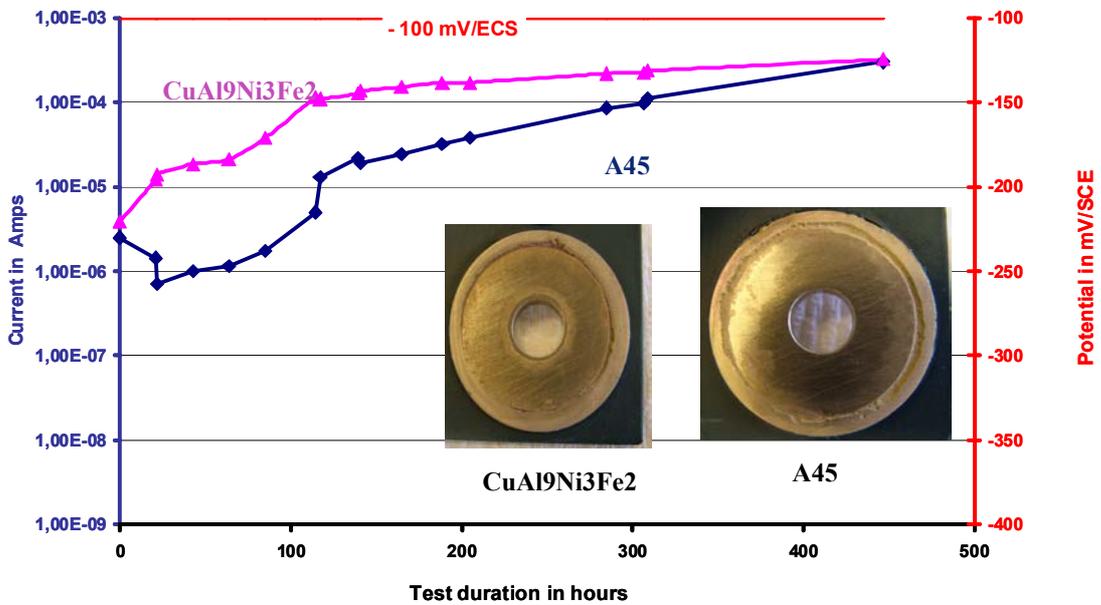
Figure 14
Crevice corrosion initiation in natural sea water (ambient temperature)
Comparison between A45 and CuAl9Ni3Fe2
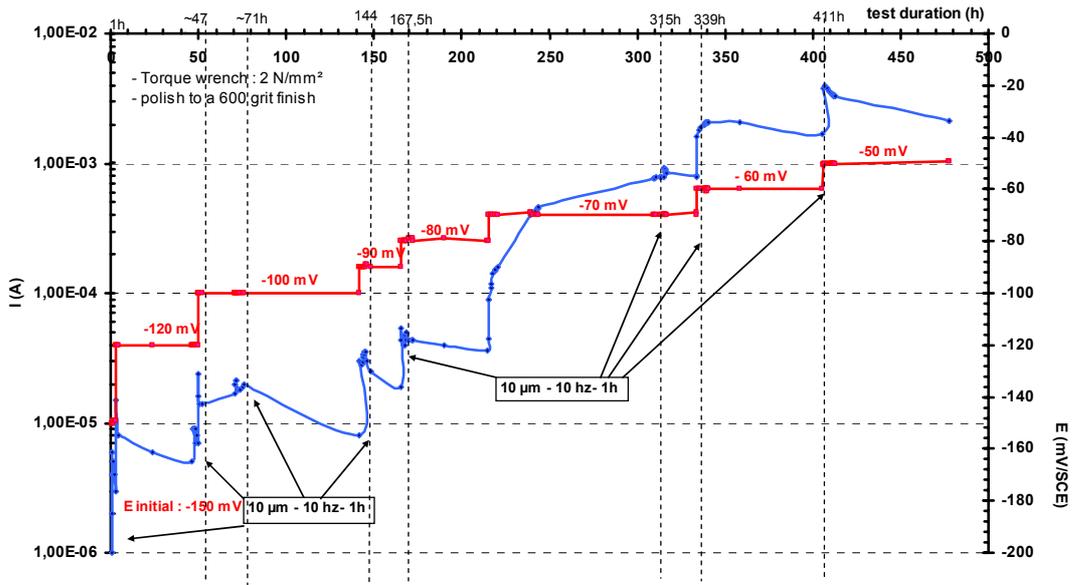
Figure 15 : Nibron - Crevice corrosion test under fretting in natural sea water 25°C
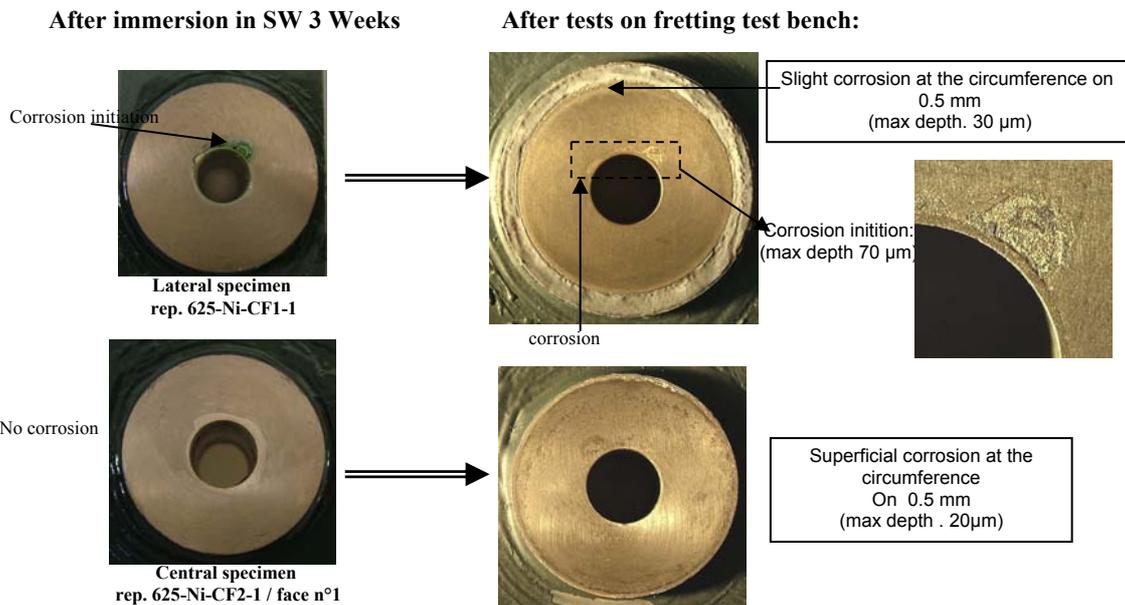
Figure 16 : Nibron – Specimen examination after crevice corrosion test under fretting in natural sea water (25°C)
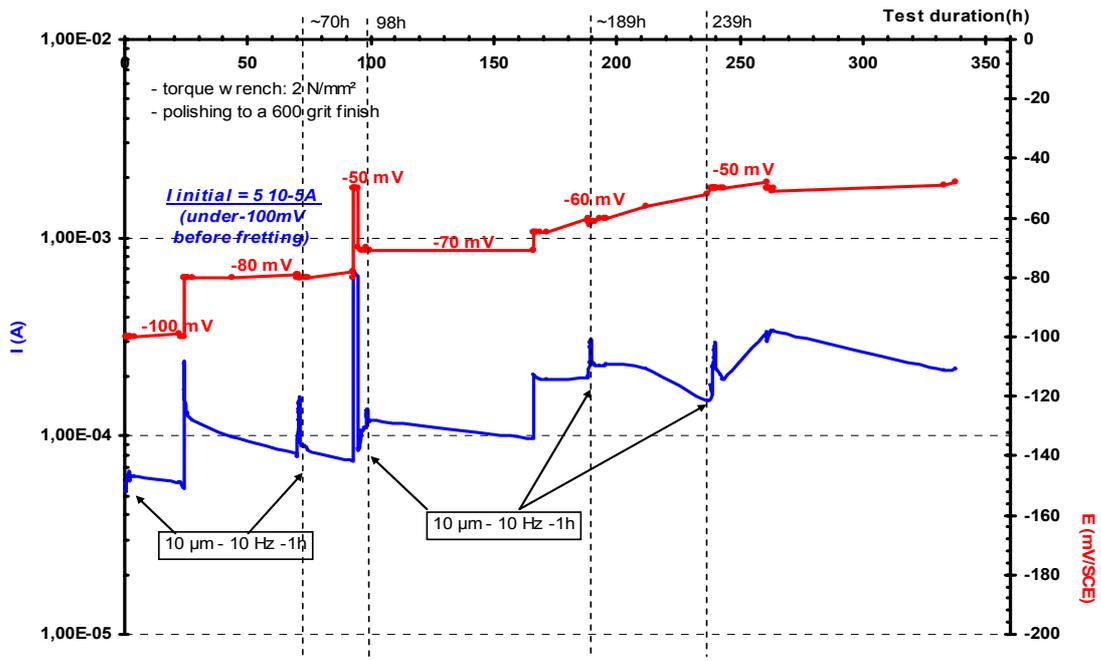
Figure 17 : *CuNi10Fe1Mn - Crevice corrosion test under fretting in natural sea water 25°C*

After immersion 3 weeks in natural SW   **After tests on fretting test bench**

Corrosion initiation

**Lateral specimen
rep. 625-CN-CF1-1**

-Slight corosion on the surface

-Localised corrosion outside the interface close

-to the interface (max depth: 0.24 mm)

**Central specimen
rep. 625-CN-CF2-1/ face n°2**

No corrosion

-Superficial localised corrosion at the circumference on 3 mm
(max depth : 0.03 mm)
And some pittings
(max depth 0.14 mm)
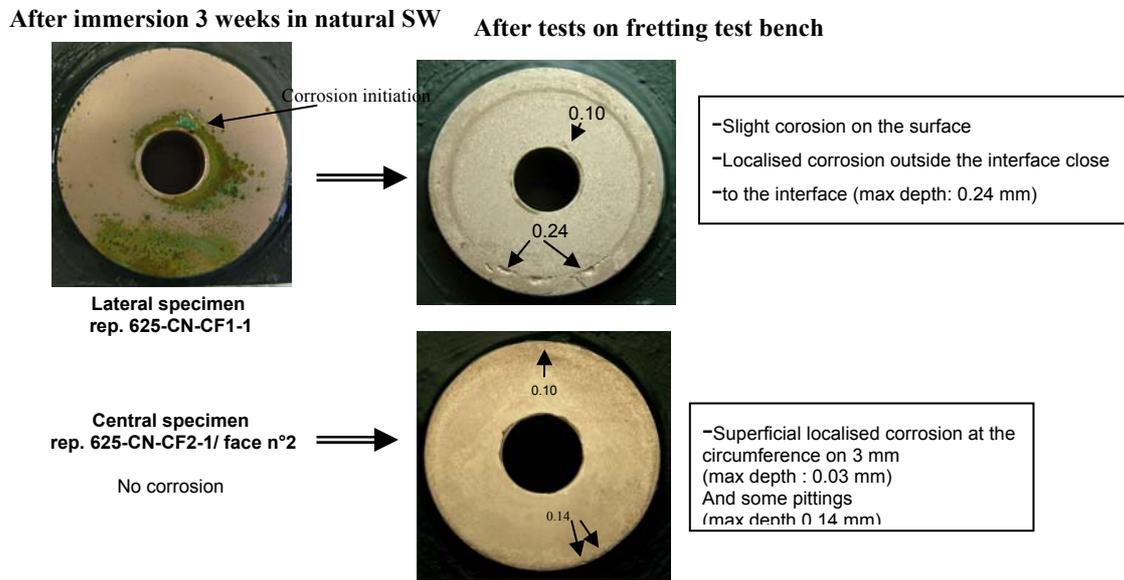
Figure 18 : CuNi10Fe1Mn – Specimen examination after crevice corrosion test under fretting in natural sea water (25°C)
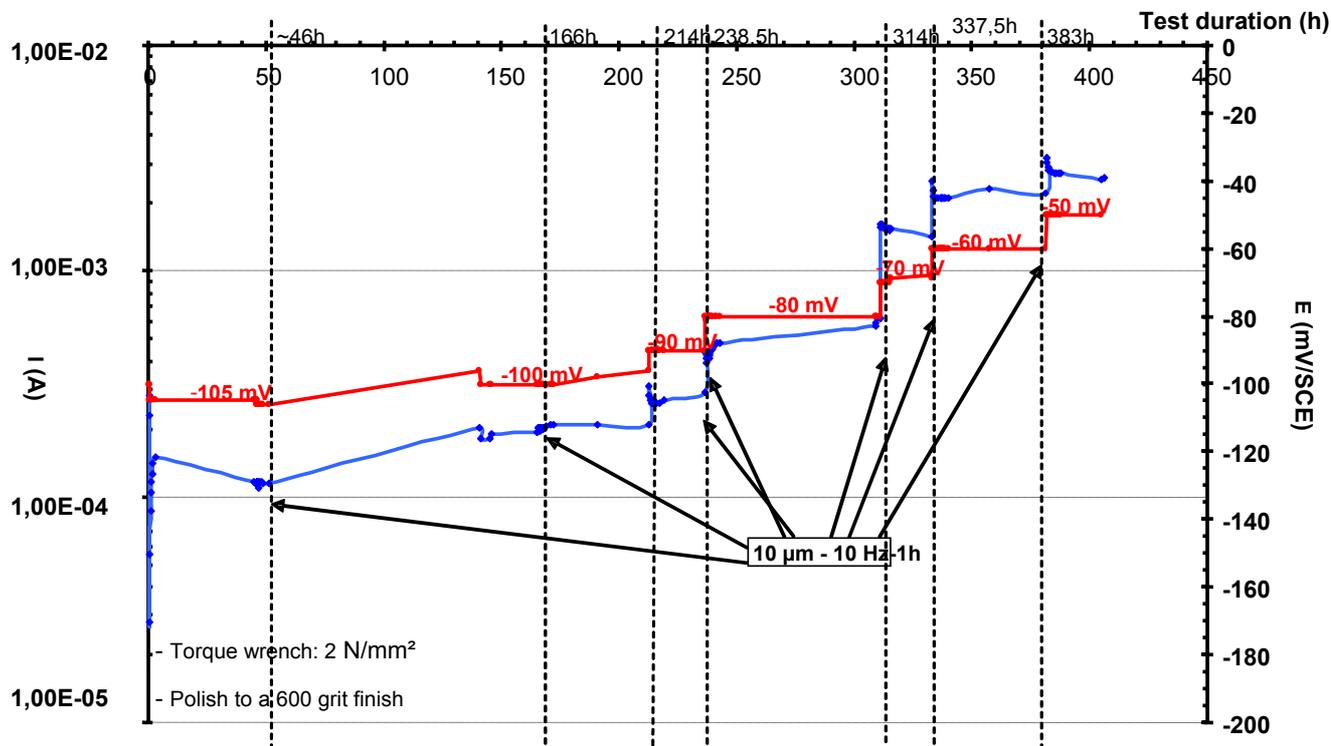
Figure 19 : A45 - Crevice corrosion test under fretting in natural sea water 25°C
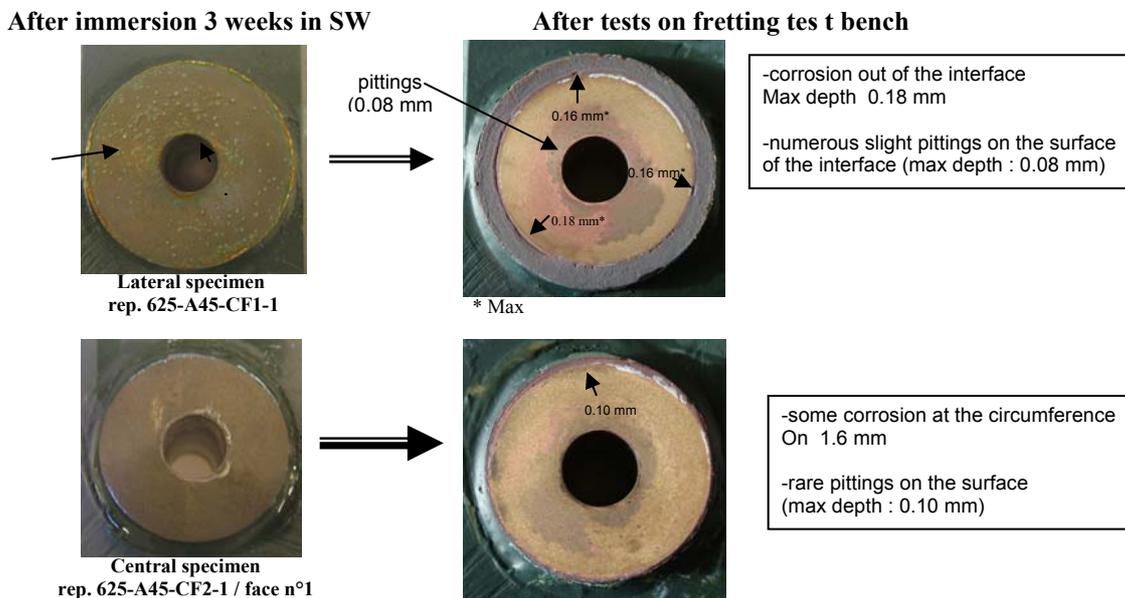
Figure 20 : A45 – Specimen examination after crevice corrosion test under fretting in natural sea water (25°C)
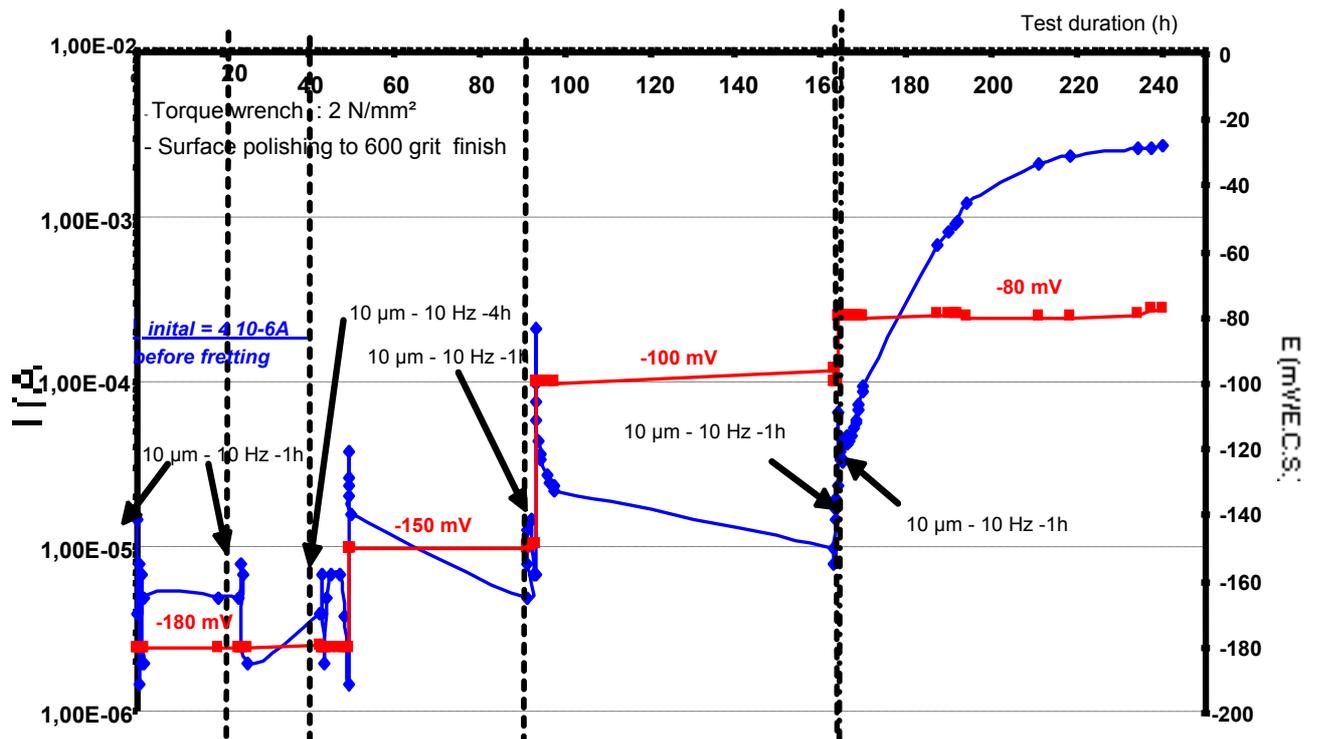
Figure 21 : CuAl9Ni3Fe2- Crevice corrosion test under fretting in natural sea water 25°C
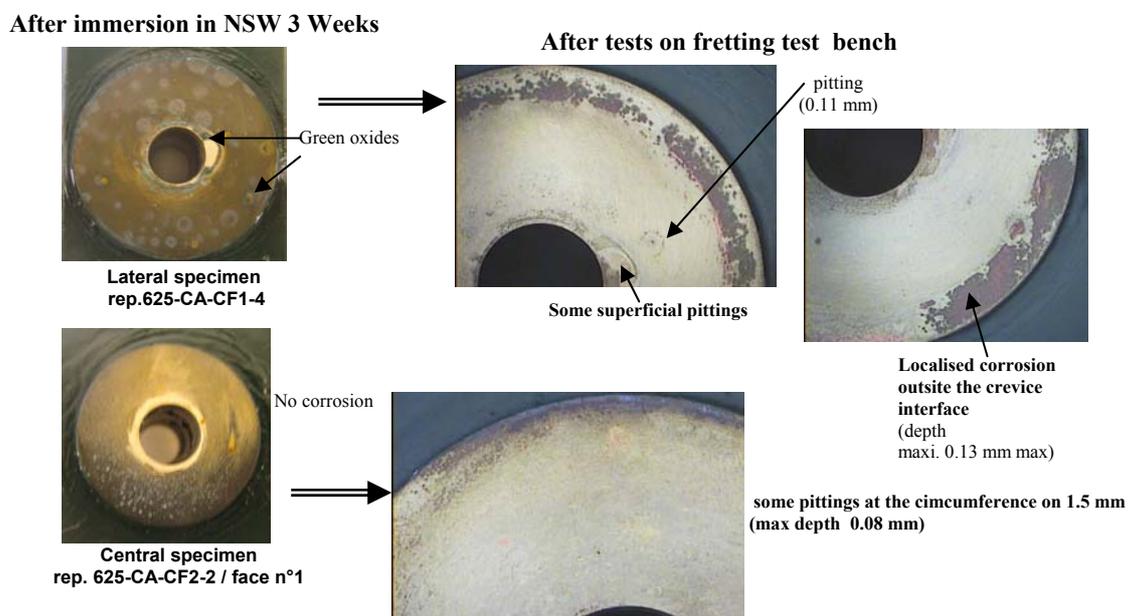
Figure 22 : CuAl9Ni3Fe2 – Specimen examination after crevice corrosion test under fretting in natural sea water (25°C)

Cu Al9 Ni3 Fe2

Sea Water + 170 ppm NH$_3$ - 1 000 hours → 44 Cracks

Sea water + 1700 ppm NH$_3$ - 120 hours → 45 Cracks

A 45

Sea water + 170 ppm NH$_3$

1 000 hours → 5 No Cracks / 6 No Cracks

5 000 hours → 7 No Cracks / 8 No Cracks

Sea water + 1700 ppm NH$_3$

1 000 hours → 9 Cracks / 10 Cracks

5 000 hours → 11 Cracks / 12 Cracks

No crack observed on A45 in natural sea water after 5000 h as CuAl9Ni3Fe2 exhibits cracks after 7500 h
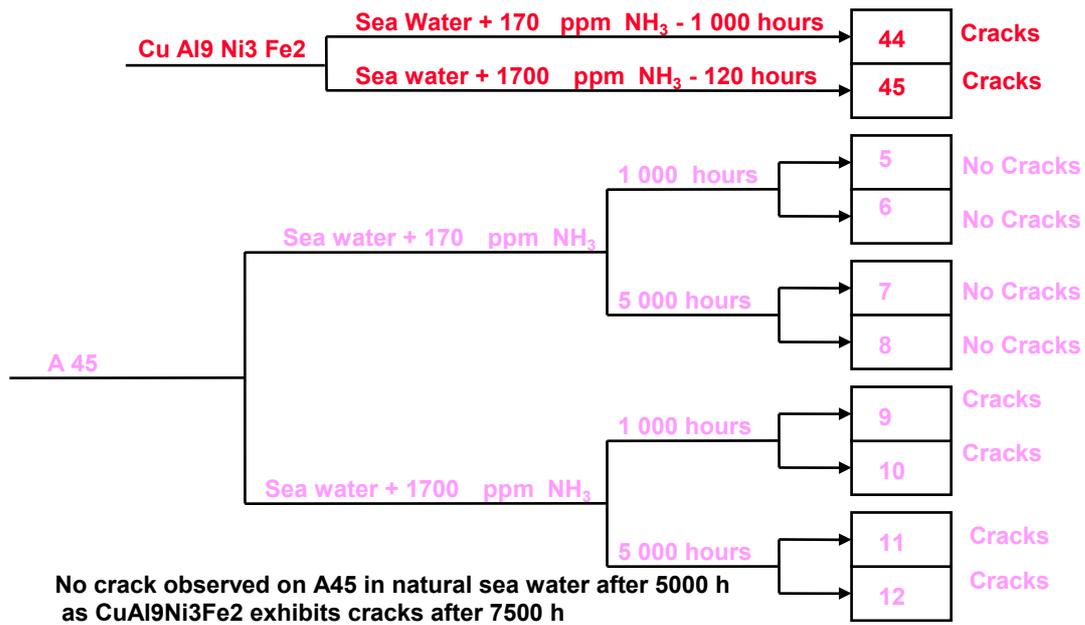
Figure 23 : *A45 and CuAl9Ni3Fe2 -U-bend test results in natural sea water and polluted sea water with ammonia*

Cu Al9 Ni3 Fe2
Specimen 45
Sea water + 1700ppm NH$_3$ - 120 hours

A45
Specimens 9 et 10
Sea water + 1700 ppm NH$_3$ - 1000 hours
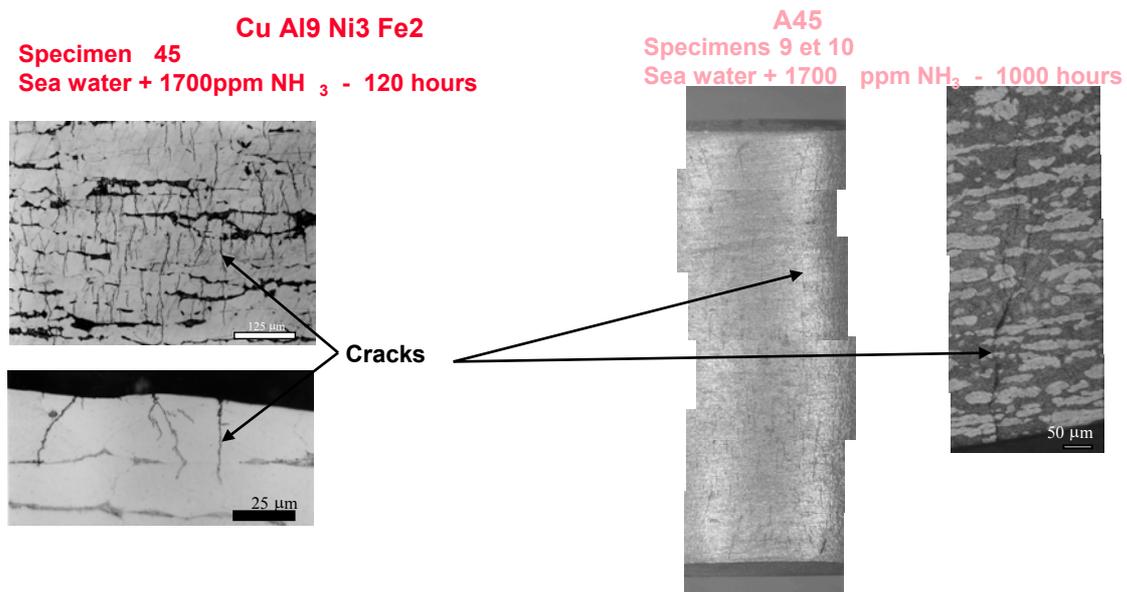
Cracks

Figure 24: *A45 and CuAl9Ni3Fe2 -U-bend test results in natural sea water and polluted sea water with ammonia- Specimen examinations*

Sea water + 170 pp de ₃ - 1 000	17 et	No cracks
Sea water + 1700 ppm de NH$_3$ - 1 000	21 et	No cracks
C Ni 90 - 10		
Sea water + 170 ppm de NH$_3$ - 5 000	19 et	No cracks
Sea water + 1700 ppm de NH$_3$ - 5 000	23 et	No cracks

Sea water + 170 ppm de NH$_3$ - 1 000	31 et	No cracks
Sea water + 1700 ppm de NH$_3$ - 1 000	35 et	No cracks
Nibron		
Sea water + 170 ppm de NH$_3$ - 5 000	33 et	No cracks
Sea water + 1700 ppm de NH$_3$ - 5 000	37 et	No cracks

No cracks on CuNi 90-10 and Nibron observed after 5000 hours in natural sea water

Figure 25: *Nibron and CuNi10Fe1Mn -U-bend test results in natural sea water and polluted sea water with ammonia-*

CuNi 90-10
Specimen 20
seawater + 170ppm NH $_3$ - 5000 hours

Nibron
Specimen 34
Seawater + 170ppm NH $_3$ - 5000 Hours

250μm

250 μm

Secimen 24
Sea water + 1700ppm NH $_3$ - 5000 Hours

Specimen 37
Sea water + 1700ppm NH $_3$ - 5000 Hours

250μm

250 μm
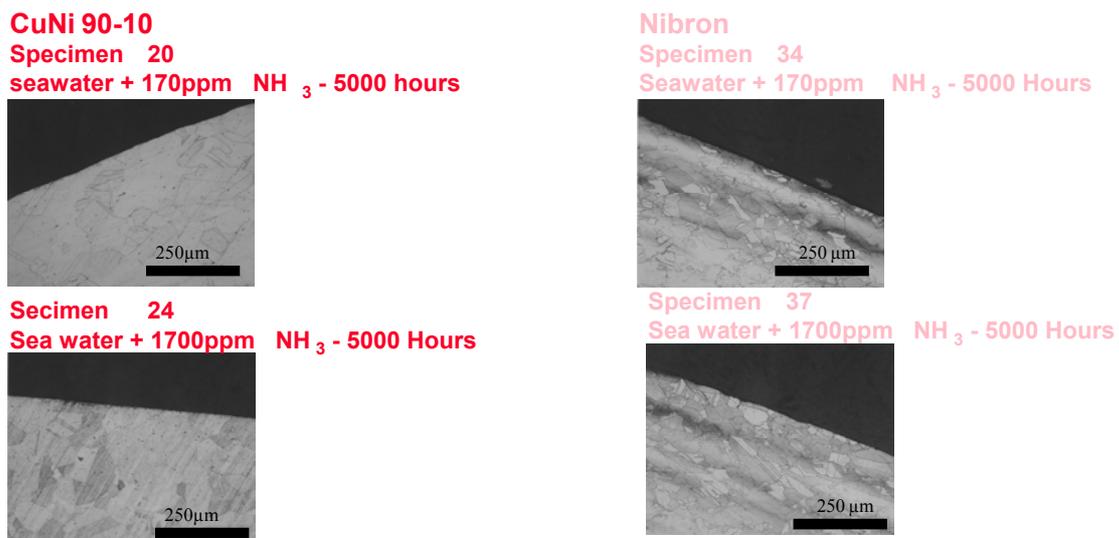
Figure 26: *Nibron and CuNi10Fe1Mn -U-bend test results in natural sea water and polluted sea water with ammonia-Specimen examination*