Corrosion of three propellers in a boat operating in Ria de Aveiro (Portugal)

university of aveiro
theoria poiesis praxis

A.C. Bastos,[1] C. Lemos,[2] O. Karavai,[1] M. Starykevich,[1] A. Rocha,[1] D.E.L. Vieira,[1] M. Oliveira,[1]
R. Sampaio,[1] C. Gomes,[1] M.G.S. Ferreira[1]

1. Departamento de Engenharia de Materiais e Cerâmica and CICECO – Aveiro Institute of Materials, Universidade de Aveiro, 3810-193 Aveiro, Portugal
2. Plataforma do Mar, Universidade de Aveiro, 3810-193 Aveiro, Portugal

Introduction

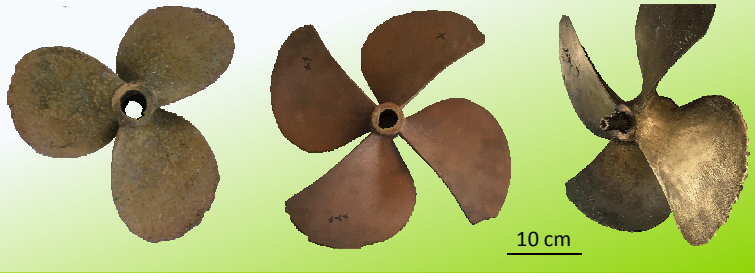
After 17 years in service, the propeller of a boat operating in Ria de Aveiro (Propeller 1) was replaced by a new one (Propeller 2), with the same manganese bronze composition (in fact a brass, ~58Cu39Zn) but with a new geometry - 4 blades - for better performance and smoother movement. Unexpectedly, in less than 6 months, Propeller 2 presented heavy and fast corrosion. A third propeller (Propeller 3) had to be installed, similar to Propeller 2 but with a small change in the blades to give 2.54 cm extra pitch. After one year in service, this propeller showed no obvious signs of corrosion but revealed clear evidences of erosion and strong cavitation.

The boat (pictured on the left) has a wooden structure and the hull is covered with copper plates. Cathodic protection with zinc anodes was applied along with Propeller 2.

Propeller 1
17 years in service
Diameter: 44.8 cm
3 blades
Manganese bronze

Propeller 2
6 months in service
Diameter: 45.7 cm
4 blades (pitch = 33 cm)
Manganese bronze

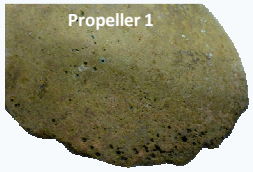
Propeller 3
9 months in service
Replica of propeller 2
but with pitch = 35.5 cm

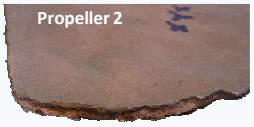


Corrosion

Erosion

Erosion of propeller edges due to navigation in shallow waters, with sand, stones, shells and debris.





Disintegration of the blades edges by erosion due to low strength and low hardness provoked by dezincification.

Propeller 3

After 2 months in service, a strong impact removed part of the blade edge.

Erosion in Propeller 3 after 9 months of activity.

Cavitation

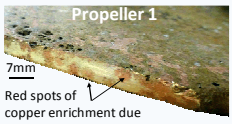
Propeller 3

Cavitation in propeller 3 after just 2 months of operation.

Propeller 1: some holes at the periphery may have been caused by cavitation.

Propeller 2: no cavitation, either because there was not enough navigation time or because the angle of the blades was smaller compared to Propeller 3 (giving smaller pitch).

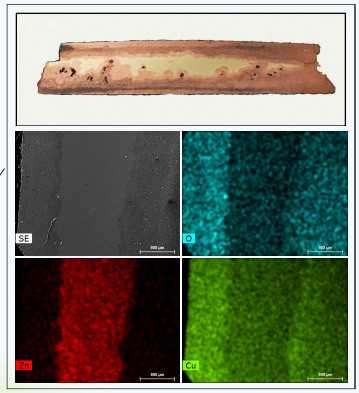
Dezincification



Red spots of copper enrichment due to dezincification.

Thick and compact external layer rich in copper and copper oxides. This layer appeared in just a few months. The attack was too heavy for being of natural cause. Moreover, with Propeller 2, cathodic protection was attempted and the zinc anodes and the steel supports were also dissolved.

Hypothesis: *Unaware electrical contact while in the dock (mains power or another boat with active cathodic protection) turning this boat into an anode, leading to fast oxidation of all metallic parts, including the propeller.*



Propeller 3
No signs of dezincification after 9 months of operation

Electrochemical response

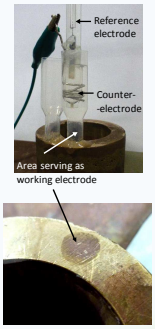
Experimental details

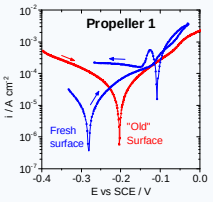
Polarization curves were obtained with an Autolab PGStat 302N potentiostat, using electrochemical cells in a 3-electrode arrangement: a delimited area of the propeler as working electrode, a platinum counter electrode and a saturated calomel electrode (SCE) as reference. Measurements were performed after 1 hour and 1 day of immersion, in water from Ria de Aveiro (pH=7.9, κ = 46 mS cm^{-1}, T= 25.5 °C), quiescent and open to air, with a scan rate of 1 mV s^{-1} and independent anodic and cathodic sweeps in fresh new areas.

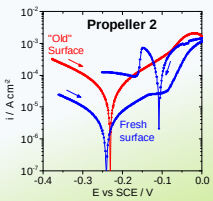
Propeller 1

Propeller 2

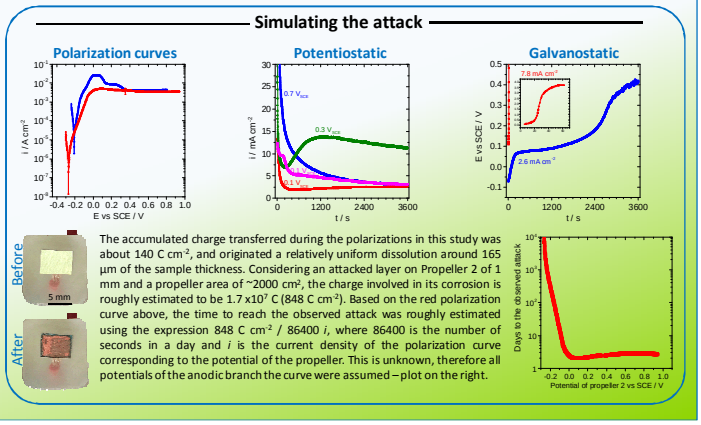
Electrochemical cell







Simulating the attack



The accumulated charge transferred during the polarizations in this study was about 140 C cm^{-2}, and originated a relatively uniform dissolution around 165 µm of the sample thickness. Considering an attacked layer on Propeller 2 of 1 mm and a propeller area of ~2000 cm², the charge involved in its corrosion is roughly estimated to be 1.7 x10^{7} C (848 C cm^{-2}). Based on the red polarization curve above, the time to reach the observed attack was roughly estimated using the expression 848 C cm^{-2} / 86400 *i*, where 86400 is the number of seconds in a day and *i* is the current density of the polarization curve corresponding to the potential of the propeller. This is unknown, therefore all potentials of the anodic branch the curve were assumed – plot on the right.

Conclusions

- The intensity and morphology of the attack of Propeller 2 (uniform and thick layer by dezincification) suggest unaware electrical contact while in the dock (or with another vessel with active cathodic protection) turning the boat into an anode, leading to fast oxidation of all metallic parts, including the propeller.

- The cavitation found in the third propeller after 1 year of operation seems to result from a change in the blades angle, which increase pitch but also create conditions for cavitation. Numerical simulation can identify those conditions and help improve the propeller design.