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A REAL CASE STUDY ON THE STATE OF CORROSION OF THE SPANISH BOATS

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A REAL CASE STUDY ON THE STATE OF CORROSION OF THE SPANISH BOATS

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Key words: boat, corrosion, Spanish, case study.

ABSTRACT

In this real case study we analyze various corrosion problems encountered in Spanish fleets and present possible solutions. As a first step, we developed a statistical analysis of the north Mediterranean Sea fleets to define the age of the vessels, hull construction material and main activities involved. As a result, different corrosion problems were identified as well as solutions like paint, sacrificial anodes and impressed currents, and of course, improved design. Generally, we can state that, according to the results obtained, a series of incidents have increased the repair and maintenance costs of the vessels in the area under study.

I. INTRODUCTION

New models to define the corrosion level of ship structures are related to the weather conditions [13, 20]. New parameters were considered, such as, relative humidity, chloride level and temperature.

The main results revealed that the significant parameter influencing corrosion is moisture and that this parameter is implemented by contaminants like sodium chloride and the duration of the exposure to wetness. Finally, we concluded that different environmental variables of each route need be considered during ship design [23].

To prevent such corrosion in ships, various hull construction materials were analyzed, for example, steel corrosion by coal and iron ore in a bulk carrier [9]. These results showed that the corrosive effect increased with water content, and that the influence of chloride and sulphate concentration, and to a lesser extent, particle size distribution, is dependent on the quantity of moisture.

The same steel when analyzed under high temperature and fresh water [10, 14, 18, 19] showed a clear concurrence with the model's prediction in environmental temperature ranges from 0°C to 30°C. Particularly, three different environments can be found on board; immersion in seawater, exposure to an enclosed atmosphere and exposure to porous cargoes. Consequently, this time, other parameters were identified that influenced this corrosion; cargo ratio, ballast ratio, trade route, coal corrosivity, frequency of cargo changes, type of corrosion protection and member location.

To identify which the better materials to be employed in shipbuilding are, various analyses were done of the hull, subjecting it to corrosion and fatigue [2, 7, 11, 12, 17]. In this study we can find initial fatigue studies [7] and posterior real case studies [2, 11, 12, 18] performed to validate the models. Finally, we obtained a practical strategy for risk assessment of the ultimate strength capacity of an aging ship subject to structural degradation.

Once ship fatigue was analyzed, different materials like composite [6, 21] and aluminum materials [8] were proposed. Despite the wide range of composite material applications some disadvantages were observed. For example, replacement of most naval structures with composite materials is a complicated and slow process.

Other problems including lack of design rules, difficulty of application of scaling laws with composite materials, and finally, a clear lower strength and fatigue resistance were noted. Therefore, composite structures are required to pass strict regulations for air-blast and underwater shock damage resistance that have to be implemented with future research works.

However, the aluminum hull [8] was analyzed in recent years, testing aluminum alloys in seawater at 23 and 60°C. These results showed a low corrosion rate for application in marine environments due to the intermetallic particles in the aluminum alloys.

Finally, the hull is not the only ship structure that is affected by corrosion. Equipment affected by corrosion include the engine [5] propeller [3, 16], hold frames [22] and finally, pipes and distillation plants [1].

Considering this, diesel engine exhaust scrubber materials were tested [5]. Specifically, titanium and super-austenitic stainless steel were tested to study their capability to sustain thermo-hydraulic conditions of the scrubbing system. These results showed that titanium can support the corrosive condi-

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tions, including the crevice geometry areas.

In contrast, new materials to reduce cavitation effect in propellers were investigated. For example, the microstructure of nodular cast iron on cavitation corrosion under natural sea water [3] and some repair tasks by welding methods in propellers were analyzed [16]. These welds showed better cavitation erosion resistance than the base metal.

Finally, hold frames of cargo holds of coal and iron bulk carriers were studied [22]. We discovered that the shape of the corrosion pit is always the same while the other parameters like tensile strength did not change after use.

In desalination plants [1] the main problems were the heating and evaporating processes of seawater. After much research, they were found to be related to process control due to excessive water evaporation.

As protection from the different corrosion processes the best options were found to be cathodic protection [24] and paints [4]. However, it is vital that the paints are employed on different steel surfaces with a shopprimer. After different welding and cutting processes appropriate surface treatments and painting procedures are applied to each specific area of exposure of the ship. Importantly, it is possible to use specific paint to each particular type of ship.

From this research work it was concluded that the only environmentally acceptable method for application on ships is the old alternative of copper-based, antifouling paints [4].

The final step in the research on ship corrosion deals with corrosion protection methods. When we consider the more common corrosion protection methods, the cathodic protection system [24] is noteworthy. In this system, the presence of an anode is simulated by an inert electrode connected to a rectifier which produces a current in their field.

The problem arises unless we determine the right amount of current output from the anodes to reduce the potential on the cathode to a critical level. Initial research work on cathodic protection models in ships was begun and, is still being tested today [24].

These corrosion protection methods need improvement with an adequate inspection methodology. The inspection methodology will allow us to optimize and minimize the expected fatigue damage detection delay [15].

These results showed that by increasing the number of inspections and quality, the expected detection delay can be reduced. Simultaneously, we concluded, that for a predefined damage detection delay, an optimum inspection plan based on different inspection types is more economic than one based on the same inspection procedure.

Finally, inspection plans based on probabilistic studies showed satisfactory results.

In this real case study different corrosion problems in Spanish fleets were analyzed, and the possible solutions are presented here to show the actual status of the Spanish fleet. As a first step, a statistical analysis of the north Mediterranean Sea fleets was developed to define the age of the vessels, hull construction material and main activities involved.

Table 1. Operating fishing costs at the Spanish national level.

Concept	Costs (Million)	Percentage (%)
B1. Bait, salt, ice and packaging	23.42	2.84
B2. Procurements	13.51	1.64
B3. Rigging	33.15	4.03
B4. Spare parts, repairs and maintenance	67.21	8.16
B5. Fuel and lubricant	212.96	25.86
B6. Other services	36.15	4.39
B7. Port charges	23.37	2.84
B8. Other expenses of the vessel	13.45	1.63
B9. Other non-fishing costs	25.45	3.09
Total	448.67	54.47

Table 2. Number of ships in each different Spanish community.

	Number of ships	Power (HP)	Total length (m)
Galicia	5198	450374	9.95
Asturias	339	32967	11.52
Cantabria	168	34733	18.15
P. Vasco	253	192027	27.79
Cataluña	1040	151068	12.80
C. Valenciana	697	108206	14.71
I. Baleares	432	30416	9.32
Andalucía	1750	209908	12.49
Murcia	221	18237	10.65
Ceuta	39	18906	21.09
Melilla	1	170	22.09
I. Canarias	969	93479	9.67

This study is on the fleet belonging to the Catalan community, whose boats sail and work in the north area of the Spanish country, in the northern Mediterranean waters.

A study developed by the Spanish Ministry of Agriculture and Fisheries finally concluded that the maintenance repair cost of these boats annually amounted to around 10% of the operating fishing cost. Consequently, a reduction in the maintenance costs becomes very important to reduce the annual total costs, as shown in Table 1.

II. MATERIALS AND METHODS

The methodology is centered on the importance of the technical characteristics of the Spanish fishing fleet characterised by communities.

Accordingly, our case study is composed of 318 units that were grouped according to the local community to which it belongs. Consequently, Table 2 shows the number of ships employed in our study, their power and total length, for each different Spanish community.

This Table indicates that the Catalan Community fleet occupies the third place in number and importance in Spain.

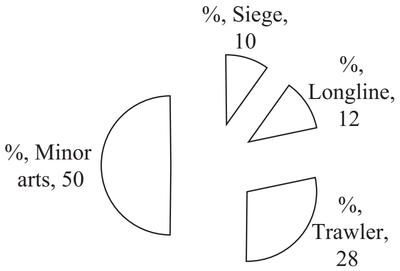

Fig. 1. Percentage of boats in accordance with its activities.

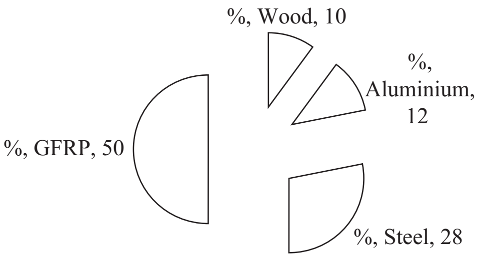

Fig. 2. Percentage of boats considering the hull materials.

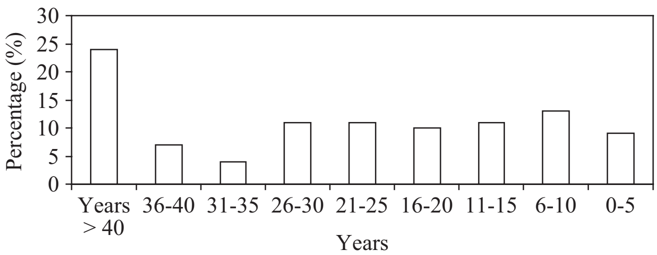

Fig. 3. Percentage of boats in accordance with fleet age.

III. RESULTS

1. Statistical Analyses

The first stage in this research was a statistical analysis of each different case study. The main results are seen in Figs. 1-3. Fig. 1 shows the percentage of votes for each different activity.

This chart reveals Minor Arts representing 50% of the fleet and Trawlers about 28%. Finally, Siege and Longline represent the remaining 22%.

When this statistical study was developed considering hull construction material, Fig. 2 was arrived at. This figure shows that glass fibre reinforced polyester is present in 50% of the fleet boats. Further, 28% of boats are made of steel while the other boats are built of aluminum (12%) and wood (10%). This indicates that to reduce costs, glass fibre reinforced polyester and steel boats are better. This information was complemented with statistical analyses of the fleet age as shown in Fig. 3. This figure reveals that 25% of the fleet boats are over 40 years old, and that at the same time, boats less than 40 years old present the same distribution with time and a mean value of 10%. From this initial information we conclude that 25% of glass fibre reinforced polyester and steel boats are the ones most susceptible to corrosion. In this context, to define the real state of this fleet, first an analysis of each different type of boat, its main problems and possible solutions proposed will be dealt with in the following sections. Specifically, the study was divided into aluminium boats, wooden or GFRP boats and, finally, steel boats.

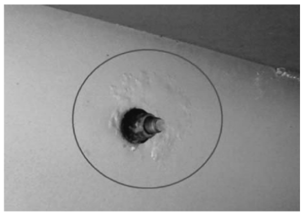

Fig. 4. Stainless steel clamp screw to hull.

Fig. 5. Failure in the patent.

2. Aluminum Hull Boats from 8 to 14 Meters Length

In 10% of aluminum boats it was found that, although it appears clean, there is a fine aluminum oxide layer which prevents adhesion of the primer, as seen in Figs. 4 and 5. Paint coating treatment of aluminum was developed more carefully than for steel. Further, primers must resist the maximal aluminum dilation with temperature and surfaces. This treatment is very sensitive to the behaviour of aluminum as an anode, causing peeling and blistering during treatment.

3. Wooden or Glass Fibre Reinforced Polyester (GFRP)

In small fishing boats, less than 8 meters in length in the engine hatch, some tightness and a few leaks were observed, as we can see in Figs. 6-9. Therefore, to reduce corrosion problems, a minimal sealing or closing of the hatch engine with a minimum coaming height of 100 mm was performed. Further, generalized corrosion in the engine was found and related to the direct inflow of sea water through the inlet valve, showing the absence of sea inlet filters. The solution was to paint after proper preparation of engine surface taking into consideration the manufacturer's specifications concerning the position, size and duration of the sacrificial anodes. In wooden boats, some corrosion in the rods of keel bolts and engine bolts was observed. Consequently, stainless steel bolts were employed from this new complement to reduce the maintenance.

Simultaneously, corrosion was observed in the sea inlet and bottom valves, as evident in Fig. 6, thus concluding that sea

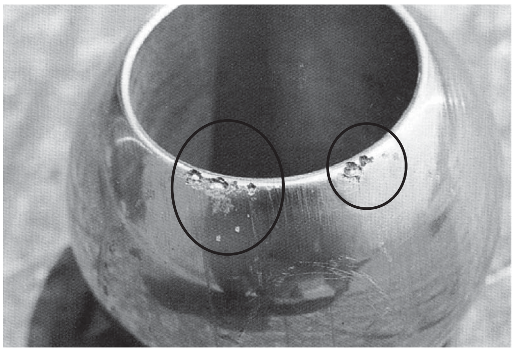

Fig. 6. Pitting corrosion on the ball of a foot valve 1 of stainless steel.

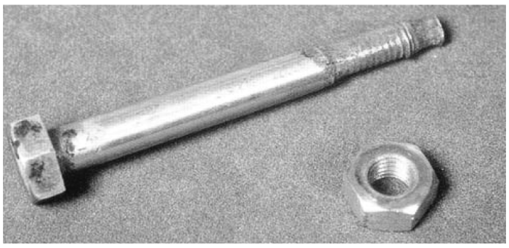

Fig. 7. Stainless steel bolt.

Fig. 8. Inboard engine.

Fig. 9. Fishing boats between 8 and 14 meters.

Fig. 10. Untreated copper pipe.

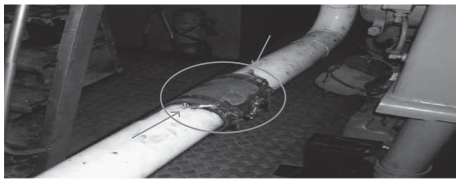

Fig. 11. Vibration with jumper cap.

Fig. 12. "Alador" position.

inlet damaged valves are of low quality, exactly similar to the quality of the valves employed in irrigation. Therefore, they were replaced. Finally, corrosion in hydraulic oil tanks and in fuel tanks was related to the lack of grounding and corrected by connecting the hydraulic tank and servo to mass, and painting after suitable treatment.

In wooden or glass fibre reinforced polyester from 8 to 14-meter long vessels, the main problem observed was to prevent the high corrosion in aluminum tooling, such as windows, wipers and engine control panel, as we can see in Figs. 10-12. The initial analysis revealed that the use of aluminum windows, typically employed in land application, showed poor coating treatment that consequently led to a rapid deterioration of these elements. Employing aluminum materials in naval constructions would increase the life and robustness of these elements. Particularly, some equipment under special conditions were considered. For example, the "alador" is an element in constant contact with splash and spray, and therefore, it needs to be protected with suitable paint treatment before bringing it into contact with mass. In

Fig. 13. Corrosion in steel rudders and servo drive components.

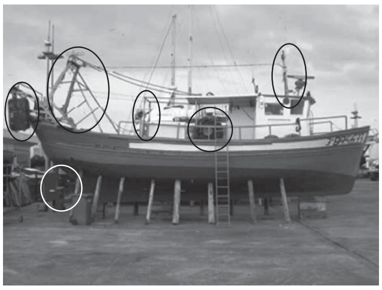

Fig. 14. Corrosion in the fishing system materials, structure or idler winches, trawl winches, cables and towed trawl doors.

these very same vessels, metal pipes were replaced by plastic pipes or hoses in the engine room as they do not require qualified staff for installation and repair.

At the same time, electrical continuity had disappeared and eddy currents appeared among the few remaining metal installation elements, such as pumps, valves and throught-hull filtering, between others. These elements were not connected to the ground or to a sacrificial anode, which lead to varying potential differences between metals, and thus, the weakest metal presented corrosion problems. Finally, as plastic or neoprene pipes, without electrical continuity, were now installed, the copper fuel lines were properly painted and parasite currents began to be generated among the different elements. The main solution was to connect these components to the mass and sacrificial anodes. Another general recommendation was to replace the low-quality stainless steel screws of AISI 304 with AISI 316. However, it must be noted that while the AISI 304 looks similar to the AISI 316 it presents less weldability and corrosion resistance.

Another parameter observed is an increase in the consumption of diesel engine anodes. To solve this problem, the installation of an anode in the sea inlet filter or waterproofing the engine cooling line with an anode connected to mass was proposed and tested. Further, the sea inlet valve was connected to the other elements put to mass. Thus, the life of the anode output could be increased from 6 to 8 months.

In this research on wooden or GFRP vessels from 12 to 24 meters in length, three groups were studied: trawl wooden hull boat, drag GFRP hull vessels and purse seine wood or GFRP fishing boats.

In the trawl wooden hull boat, Figs. 13-17, steel bolts were replaced with stainless steel bolts and, at the same time,

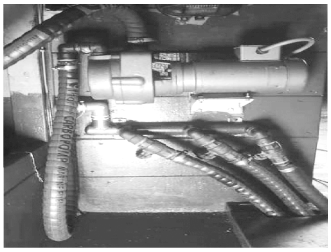

Fig. 15. Corrosion in pipe services and in wash down, bilge and fire pumps.

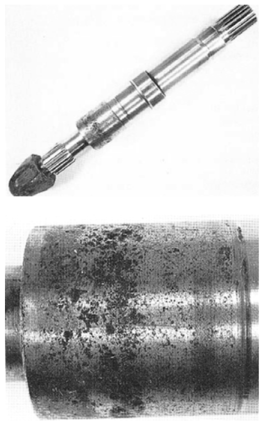

Fig. 16. Corrosion of connecting bolts or keels.

Fig. 17. Fretting or pitting corrosion in the tail axis.

corrosion in the fishing system materials, structure or idler winches, trawl winches, cables and towed trawl doors was reduced in the main engine bed, corrosion was reduced if they were connected to sacrificial anodes and, as in the previous sections; corrosion in the metal pipes was prevented.

To protect steel rudders and servo drive components from corrosion, the best solution was to place an anode in both the rudder and the stern, near ink. Another solution was to apply a proper paint treatment, starting always with clean metal grade blasting. However, the only solution for corrosion of the tail axis was prevention. In this case study too this was the same problem that occurred over the past two years, entailing two major repairs on the tail shafts of wood boats. At the same time, a similar corrosion in the shaft and piping in drag boat hull glass fibre reinforced polyester (GFRP) vessels was observed, as we can see in Figs. 18 and 19. In these vessels, usually between 20 and 25 years, it generally presents the

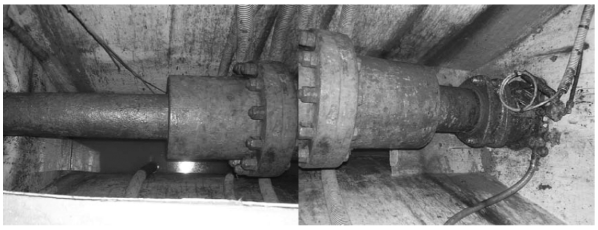

Fig. 18. Localized corrosion on the shaft and its intermediates.

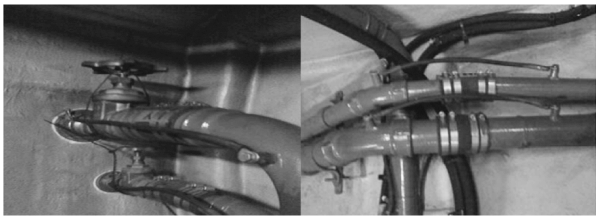

Fig. 19. Corrosion in pipe systems.

Fig. 20. Gradual corrosion of the steel hull.

current printed system to complement aft and sea inlet sacrificial anodes. Finally, the same problem in purse seine fishing wood or GFRP boats was analyzed. In these kinds of boats, different problems were observed; parasitic corrosion currents in the tail shaft due to poor cathodic protection, corrosion on the sticks or crane rigging, and finally, the electrical system.

The main solution for parasitic currents, as in the previous sections, is the installation of slide brushes and current output. In these ships, to prevent corrosion on the sticks and to protect it, a good epoxy-based paint coating was employed. Also, to connect it to the ground, the stick, the hydraulic crane and oil tank were similarly treated.

4. Steel Hull Boats

In this section we will consider three groups: drag steel hull boat, passenger boats less than 24 meters in length and siege steel hull fishing boats. In drag steel hull boats, Fig. 20, corrosion in the tail shaft was observed. In this instance, it must be noted that most of the tail axes of these vessels are mounted on AISI 316L steel.

To solve this problem the bronze shirts need to be replaced by composite materials, resulting in isolation of the tail shaft with respect to the hull. However, this phenomenon, which occurs most obviously in fibre vessels, was minimized by installing a brush holder graphite axis which sends the parasitic galvanic current to mass or directly to the hull.

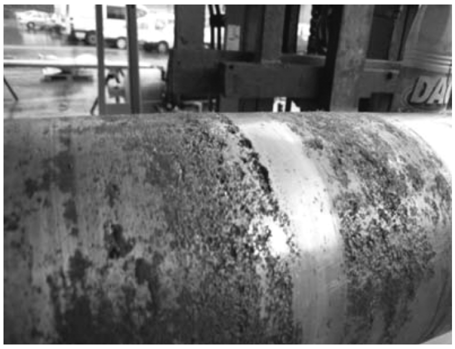

Fig. 21. Corrosion tail shaft.

Fig. 22. Pipe corrosion in services.

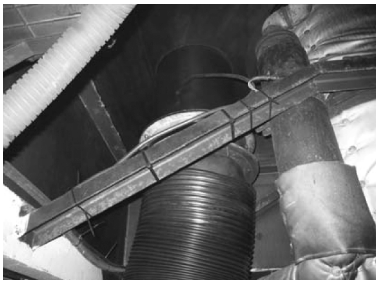

Fig. 23. Silent leaks and corrosion in the main and auxiliary engine.

By contrast, engine block cooling is performed using heat exchangers, usually multi-copper pipes which, simultaneously, are directly sea water cooled. Here, it must be noted that there are fewer problems in such kinds of systems, and most of these are related to the lack of cooler maintenance, that need to be developed by qualified personnel. A very useful protection that was proposed was the installation of a current printed system in addition to the sacrificial anodes.

In these boats, another related problem was pipe corrosion. It was later concluded that continuity in the pipes needed to be tested, especially in the transition between the antivibration neoprene caps. Further, the use of a flanged pipe was recommended, which minimized corrosion threads and leakage, providing more robust services. Next, Figs. 21-24 reveal a few examples of pipes and the electrical continuity of these links horn cap and bottom valves.

In passenger vessels, Figs. 25-28, the service pipes were

Fig. 24. Pipes and electrical continuity of these links horn cap and bottom valves.

Fig. 25. Corrosion of screws and steel frames in the underwater sight glass windows.

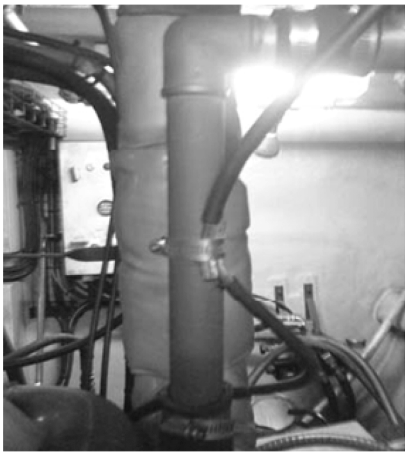

Fig. 26. Corrosion failure to protect main engine and pipes.

ground; also, it was strongly recommended to paint the pipe lines with fuel specific colours. Finally, the propeller blades were replaced with other stainless steel materials. The last problem detected in these vessels was corrosion in the main and auxiliary engine outlet gases system.

This problem was solved with an adequate surface preparation like painting, and isolation to eliminate sudden temperature changes. Also, details at the design and repair stage like must also be considered, for example, to prevent corrosion in the main engine and make and repair welds in the main engine exhaust gases system using AISI 309 stainless steel. In these vessels a great degree of corrosion was observed in the

Fig. 27. Aluminum propellers corrosion.

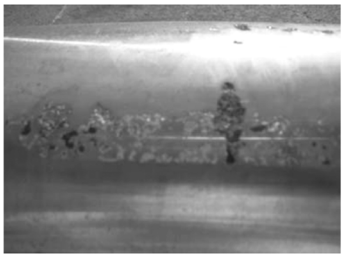

Fig. 28. Cavitations in high-speed propellers.

screws and steel frames of the underwater sight glass area. Consequently, it was replaced by AISI 316 stainless steel screws and joined to mass.

It was proposed to employ stitched windows and frames to prevent this. To reduce cavitations in high-speed propellers two options were proposed; a variation of the maximum propeller working regime or to replace and install high-strength stainless steel blades.

Similarly, siege steel hull fishing boats were analyzed. In these vessels, the main aft corrosion solution is related to suitable thickness variation check and verification by quadrennial thicknesses reports. Specifically, it needed to be done in the areas of most water corrosion, out in the stern, pockets of bilge under the main engine mount and ballast, using cement that was found below this or on its edge. However, when the oil tank treatment was done, it was developed with an appropriate application of any paint.

If suitable paints were not used major admission problems and fuel filtering due to semi-decomposed paint creating a thick paste at the bottom of the tank would occur. Finally, the faucets at the bottom of the tank to drain water impurities were strongly recommended at the design stage itself.

IV. DISCUSSION

Once the main problems and solutions adopted in this real case study were arrived at, it was easy to obtain the main conclusions for each different kind of vessel.

As seen earlier, in aluminum hull vessels two main problems were related to their construction. The first problem was that aluminum was highly sensitive to galvanic corrosion resulting from contact with other materials, usually the more noble metals. Here it was observed that the majority of auxiliary equipment was built using the more noble materials, so the aluminum acted as an anode. The second problem was related to the corrosion of the aluminium and the problems of adherence of paints and primers.

The first solution proposed to combat the aluminium corrosion was high dedication and attention given to the initial vessel design considering the contact and use of various materials and connection to mass. Aluminum boats were recommended to use a cathodic system protection by impressed currents. In this case, it became significant to put to mass all liquid transfer services, with continuity using pumps and other electrical systems.

In the case of boats over 12 meters long, using bimetallic sheets or electrical aluminum-copper terminals was strongly recommended. Also, bulkheads needed to be adequately insulated with separations or plastic gaskets. Further, this thru-hull could be constructed of plastic but their resistance to high temperatures needed to be considered.

In wooden or GFRP vessels in small fishing boats, less than 8 meters in length, a minimum number of electrical connections and electrical wires in the engine and radio-communication were to be employed and isolated from weather conditions. Finally, protective treatment by coating, preferably the same kind as used by manufacturers was recommended to be more compatible.

In ships between 8 and 14 meters in length, fitted with high-speed engines, the propellers are small in size and, when the speed increases, cavitations can occur. There are only two solutions for this problem: reduce the speed and revolutions in the cruise or vary the propeller blade pitch.

In wooden or GFRP vessels from 12 to 24 meters in length, most problems are solved by random sampling of nails and surveying the state of the bolts, developed usually every 5 years. This corrosion is related to the fact that, nearly every steel metal element was left uncovered in these boats, and therefore needed to be replaced by stainless steel elements, like cables. Importantly, the current maintenance cost and the expected acquisition cost of new machinery were reduced by employing these changes.

In steel hull vessels, to prevent gradual hull corrosion, attention must be focused on the origin of the corrosion. Immersing a metal, such as steel, in an electrolyte, such as sea water, results in a galvanic cell that causes thickness loss in the metal due to corrosion. Here, there are two ways to minimize or cancel such corrosion; protection by suitable paints and cathodic protection.

Finally, the current legislation stipulates that metal helmets over 5 years old must pass inspection or undergo test gauges to determine the degree of loss in thickness, which should never exceed 20% of original thickness. Therefore, a metal sheet of 10 mm thickness must be replaced if, at some of its surface points, it presents a loss in thickness of 2 mm. Different surveys by ship owners have revealed that these problems are related to the following reasons:

- Lack of qualified personnel on board of ships.
- Lack of qualified personnel on land and in workshops designed to repair vessels. Sometimes due to the exorbitant cost of repairs, the owners decide to do their own repairs or simply postpone doing them.
- Lack of preventive maintenance on the boats.
- Lack of rigorous inspections and reviews carried out by the administration. (Only one inspector for all maritime provinces for 10 years).
- Lack of an industrial shipping area. It is a typical tourist area or agricultural area.
- High average age of vessels.
- Excessive fishing capacity for the current fishing potential, which causes high competition and low prices, which in turn leads to low income. All these steps result in a poor level of boat maintenance.
- Inclusion of maintenance professionals for sailing sport boats.
- Generally supplies closer to these professional vessels have access to those involved in nautical sports, a great introduction in this area but with restricted supplies and dedicated to recreation, both in design and robustness.

Particularly, the lack of qualified personnel and rigorous inspections must be met in accordance to national standards, to correct the real situation in these kinds of fleets.

V. CONCLUSION

In this research work, different corrosion problems have been dealt with and solutions like paint, sacrificial anodes, and impressed currents, and of course, better design, have been suggested. Generally, it can be stated that, in accordance with the results obtained from studying these corrosion problems, a series of incidents have increased the repair and maintenance costs of the vessels under study. Classical protection methods like cathodic protection system by impressed currents and put to mass and new standards of modifications by qualified personnel coupled with rigorous inspections were proposed. In particular, it must be highlighted that corrective measures of national and international standards need to be implemented to the real situation faced by these kinds of fleets.

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