COBEM 2021 26th International Congress of Mechanical Engineering
ABCM Associação Brasileira de Engenharia e Ciências Mecânicas
November 22-26, 2021, Virtual Congress, Brazil

COB-2021-1741
METHODOLOGY FOR MEASURE THE WEAR RESISTANCE OF ANTIFOULING PAINTS

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Abstract. *Anti-fouling paints, which are intended to prevent the growth of organisms, are applied on ship hulls and on many static structures that are submerged, including: gates, piers, aquaculture systems, pipelines and drilling platforms. Regardless of its mechanical properties, the coating must remain perfectly adhered to the substrate to act as a genuine protective layer against microorganisms. No studies have been found that evaluate the wear resistance of these coatings, especially the wear caused by the ship's contact on the side of the dock while docking. The goal of this work is to develop a methodology to evaluate the wear resistance of antifouling paints. In order to simulate the contact stress of the ship on the fenders, an apparatus was developed that consists of a 230 mm in diameter and 12.7 mm thick rubber-coated disc that rotates in contact with the specimen partially immersed in distilled water. The tangential velocity and contact pressure can be adjusted according to the movement and efforts developed by the ship during docking. Five commercial paints were evaluated. The paints were applied on marine carbon steel plates (ASTM 131) with dimensions of 200 x 250 x 3 mm, properly prepared and cleaned. The painting procedure strictly followed the manufacturer's recommendation. Then, the specimens were cut to dimensions 76 x 25 x 3 mm. The normal load, applied by dead weight, was 120 N and the rotation of the disk was 25 rpm. The test time was 20 minutes. Penetration tests were also performed with Rockwell-C indenter and 150 kg load. The wear was measured by evaluating the area of paint removed. For that, an image analysis software was used. The results showed that the methodology was able to assess the wear resistance of the paint. It was possible to rank the five paints with respect to their wear resistance. The penetration tests showed that cracks or fissures could occur due to high localized stress in some paints. These failures are stress concentrators that can intensify wear and shorten the life of the coating. The developed methodology can help to select antifouling paints, predict the paint life and reduce maintenance costs.*

Keywords: *Anti-fouling paints, wear, ship hulls, adhesion.*

1. INTRODUCTION

Biofouling of marine structures has been a problem across the globe as it can greatly increase economic and environmental costs (Howell and Behrends, 2006). Antifouling paints are applied to ship hulls to prevent the growth of fouling organisms. It is also widely employed on many other static structures that are submerged including: pontoons, piers, aquaculture systems, buoys, pipelines and drilling platforms (Turner, 2010).

Regardless of its mechanical properties, a paint must adhere perfectly to its substrate to act as a genuine protective layer against the environment. The deposition of protective films is always preceded by mechanical and/or chemical treatment designed to clean the surface in order to optimize the adhesion of the film to the substrate. It is also common to deposit an intermediate layer (or bonding layer) between the substrate and the final coating. The fundamental mechanisms of adherence are varied; they can include mechanical bonding, electrostatic forces, diffusion, humidification or chemical bonding (Takadoum, 2007).

According to Kavouras, et al. (2019), the lifespan of the coating depends on its resistance to mechanical damage, the erosive effects of water movement and the softening or dissolving of the paint components. However, one should also take into consideration the abrasive wear caused by contact between the hull and the pier fenders or other surfaces. The wear rate could be a method to determine the lifetime of antifouling paints.

Few articles evaluating wear rate were found, even though the wear rate is fundamental to estimate the useful life of the coating. Most articles only analyse the erosion resistance (Noui-Mehidi, et al., 2008; Kavouras et al., 2019). However, wear can occur due to the ship's contact with port fenders, maritime structures and even with ice (Cho et al, 2020).

The aim of this work is to develop a methodology to evaluate the wear resistance of anti-fouling paints simulating the contact between the ship's hull and the fenders.

2. METHODOLOGY

2.1 Materials

Five commercial paints were evaluated. Their identification, thickness and some information are shown in Table 1. The thickness of the film was measured by evaluating the cross section of the sample with the aid of optical microscopy. It was made 15 measurements of the cross section out across the entire length of the plate.

Table 1: Paint name and their respective thickness.

Paint	Thickness [μm]	Characteristics
A	231.66 ± 8.3	Self-polishing
B	233.84 ± 8.2	Silicone paint
C	256.80 ± 19.6	Self-polishing
D	232.36 ± 13.0	Self-polishing
E	140.91 ± 13.6	Acrylic paint

The paints were applied on marine carbon steel plates (ASTM 131) with dimensions of 200 x 250 x 3 mm, properly prepared and cleaned. Before the deposition of the antifouling coating, an anti-corrosion paint, called primer, was applied. Each supplier has its specific primer. The painting procedure strictly followed the manufacturer's recommendation. Then, the specimens were cut to dimensions 76 x 25 x 3 mm.

The paints A, C and D are self-polishing paints which release particles over time in order to always have the antifouling compound on the surface and maintain the surface roughness (Howell and Behrends, 2006).

2.2 Wear tests

The wear test developed to assess the adhesion and resistance of the paints was based on the Wet Rubber Wheel Test (ASTMG105-20, 2020) commonly used for abrasion tests in aqueous environment. However, abrasive particles were not used.

The test consists of keeping the sample, under the action of a dead weight, in contact with a metallic disk coated with vulcanized rubber. The disk, throughout the test, rotates with constant speed. The rubber has a hardness of 70 ± 2 Shore A. The diameter and width of the disk are 230 mm and 12.7 mm. The disc is partially submerged in distilled water in order to wet the contact and dissipate the heat. The device used is shown in Figure 1.

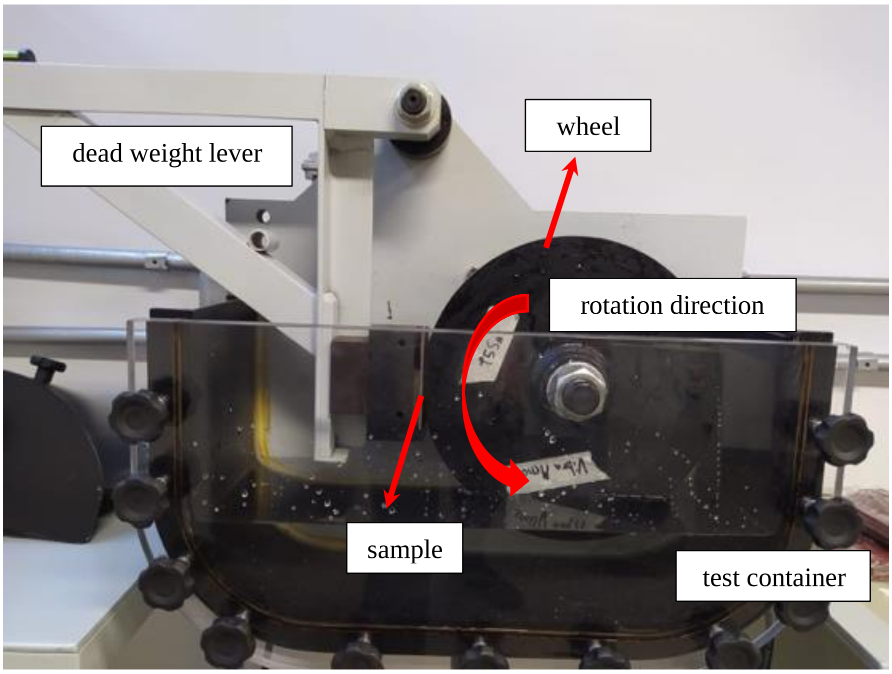


Figure 1: Equipment used in the antifouling paints wear tests.

The tangential velocity and contact pressure was chosen according to the movement and strengths developed by the ship during docking: rotation 24.7 rpm, normal load 120 N and test time 20 minutes. Sample B showed higher wear resistance and therefore the test time was increased to 60 minutes only for this sample. At least five tests were made for each paint.

Since the mass lost during the tests is too small and, in some cases, there may be adherence of the rubber material on the specimens, the wear was measured by means of the area of the paint removed. The free software ImageJ® was used to analyze the images. The size of the analyzed area was standardized at 40 x 20 mm, as shown in Figure 2.

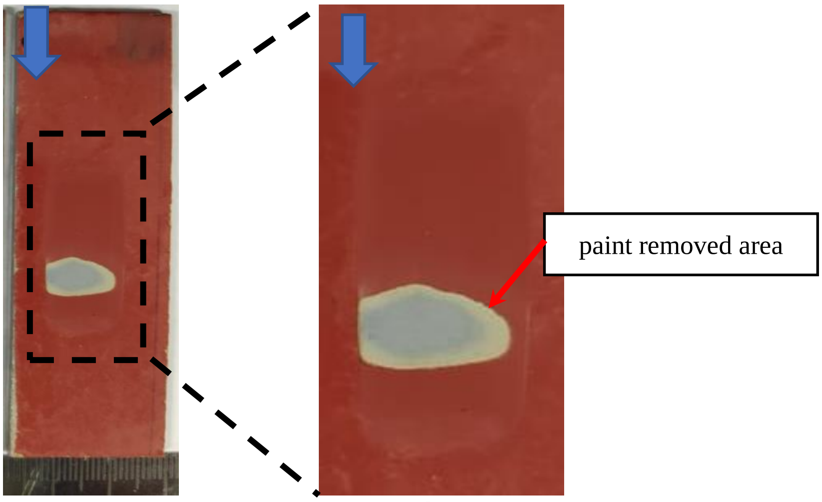


Figure 2: Methodology for assessing the removed area. (a) specimen tested and (b) area 40 x 20 mm evaluated. The arrow indicates the direction of rotation of the disc.

The area removal rate was the area removed divided by the test time. It was considered wear when the first layer, the antifouling layer, was removed. As will be seen later, in some cases it is not possible to detect the metallic substrate, but the main layer has been removed.

2.3 Penetration tests

In order to assess resistance to high stress concentrations, penetration tests were carried out. The test is similar to the conventional hardness test, in which an indenter, usually made of diamond, penetrates into the surface and after removing the indenter the damage caused to the coating and to the substrate is qualitatively evaluated. The indenter used was the standard Rockwell - C, which consists of a diamond cone with an opening angle of 120º and tip radius of 200 µm. The normal force employed was 1471 N (150 Kg). The load was applied for 5 seconds then removed. The impression was evaluated with the aid of a microscope. Five tests were performed for each coating. Care was taken in order to prevent the superficial deformation of one impression influence the other, so the indentations were away from each other at least 3 times their diameter.

3. RESULTS

Figure 3 shows the cross section of samples B, D and E. The function of the antifouling layer is simply to prevent the growth of fouling organisms and the intermediate layer, called primer, has the function of protecting marine steel from corrosion. The final coating thickness is the sum of the primer and the antifouling layer.

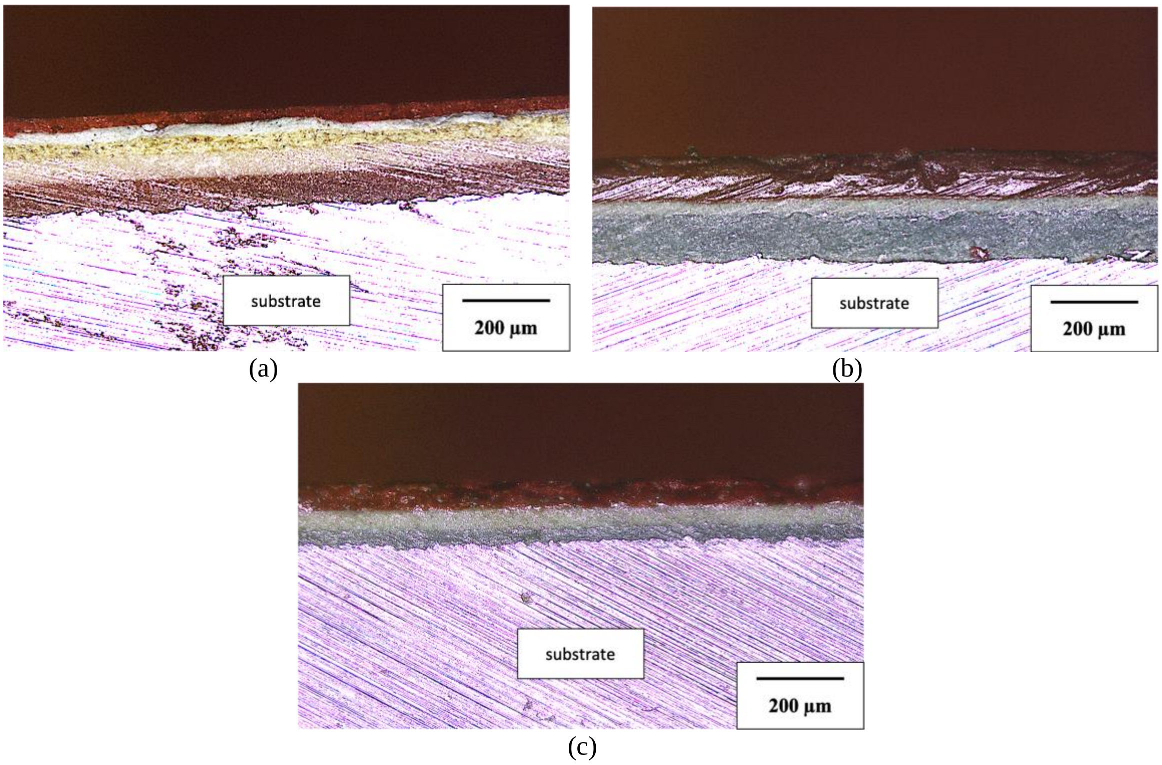


Figure 3: Cross section of samples (a) B, (b) D and (c) E.

Each manufacturer has its own anti-corrosive primer, therefore, as can be seen in Figure 3, the thickness of the anti-corrosion layer changes for each sample. But, as can be seen in Table 1, the final coating thickness was approximately the same apart from paint E, which had a thickness 78% smaller. It is also possible to note that the antifouling layer is easily distinguishable from the anticorrosive one.

Figure 4 shows the area removal rate, for each sample studied.

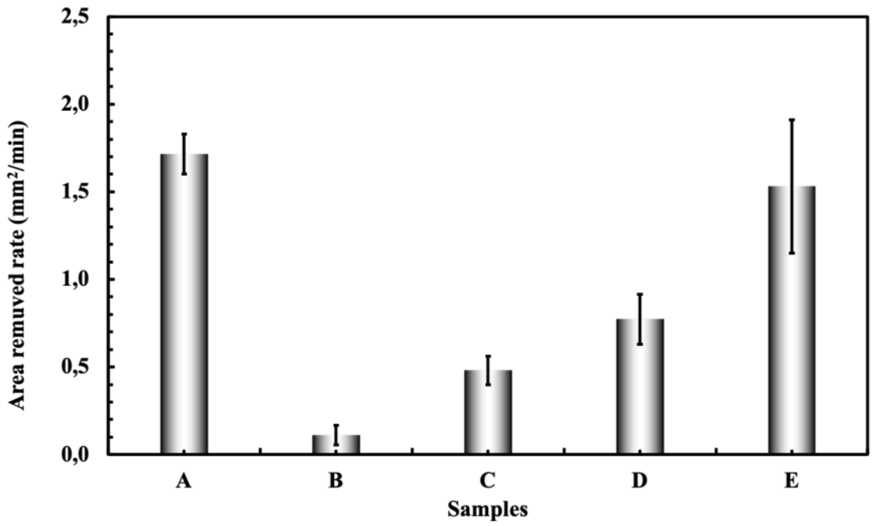


Figure 4: Area removal rate. Fn = 120 N, n = 24,5 rpm and test time = 20 min, exception of sample B which the test time was 60 minutes.

As can be seen in Fig. 4, the paint A and E presented the highest value of area removal rate, and the sample B presented the lowest wear rate under the test conditions. Under these conditions, the area removal rate of the paint A was 14 times higher than the paint B.

The higher wear rate of coating D may be due to the lower thickness of the coating, it has a thickness value of 140 µm, the other coatings had a thickness value greater than 230 µm, Table 1. The higher wear rate of paint A may be related to it being a self-polishing paint and it releases particles more easily under contact with the counter body compared to just the effect of sea waves.

As can be seen in Figure 5, the substrate was exposed on samples C, D and E. In samples A and B the antifouling paint was removed but the substrate was not exposed. The A paint showed a highest wear rate, Figure 4, however it prevented the exposure of the base metal under the test conditions. Being able to prevent the base metal exposure is essential due to the corrosion that could occur with carbon steel in marine water.

It can also be seen in Figure 5 that particles from sample A mixed with rubber particles and adhered to the surface of the specimen, this may have been caused by the self-polishing technology. However, this phenomenon was not observed in the other self-polishing samples, samples C and D. The adhesion of this mixture on the surface may cause changes in the topography that can lead to hydrodynamic changes and, consequently, increase drag (Howell and Behrends, 2006). Also, according to Holm, et al (2004), the increase in roughness can cause an increase in incrustation, which might cause an increase in drag.

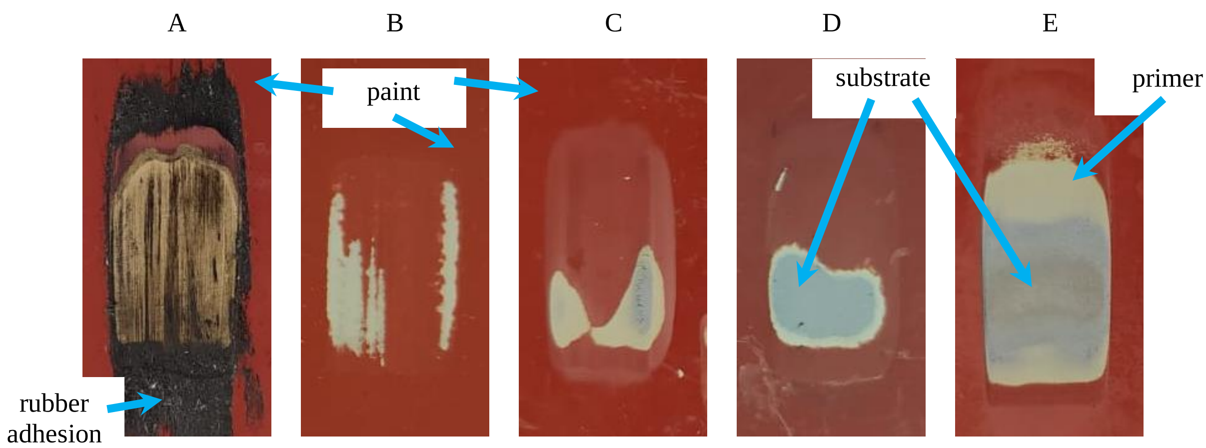


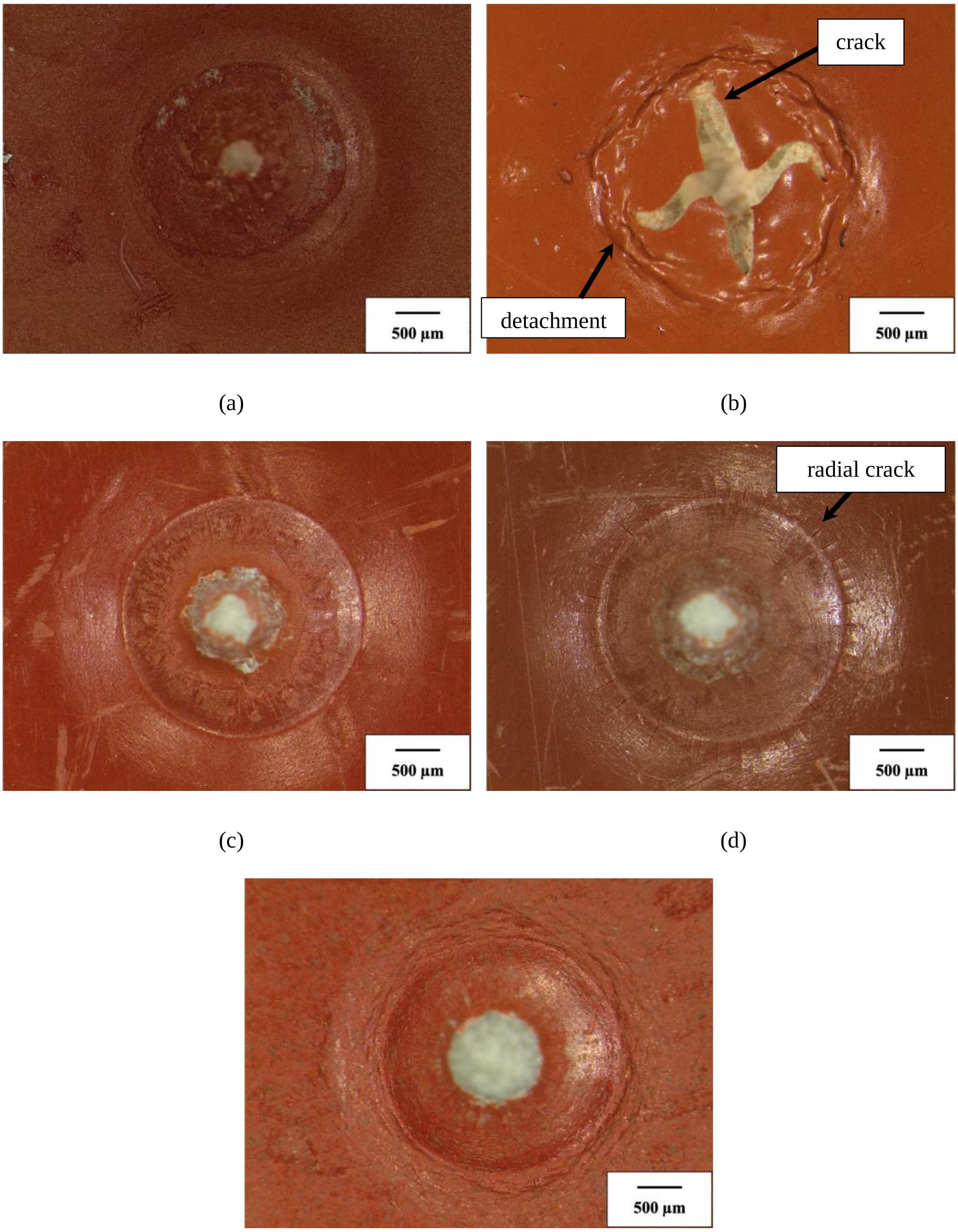
Figure 5: Example of the wear mark on each sample. Area evaluated 40 mm x 20 mm. Testing time was 20 minutes, exception of sample B which the test time was 60 minutes.

Figure 6 shows the impressions after the penetration test with the Rockwell-C indenter and normal force of 150 kg.

It can be seen in Figure 6 that all paints, apart from B, manage to remain adhered to the substrate even with the substrate deformation. It can also be seen that in the center of the impression the substrate was exposed.

Coating B had the lowest wear rate, see Figure 4, but this sample had a severe fracture in the paint after the penetration test, Figure 6b. Sample B also showed a detachment of the coating from the substrate. The implications of this phenomenon in the wear rate of the coating need to be better studied, however, the presence of a fracture in the coating can lead to an increase in wear rates as this crack can be a stress raiser.

Sample D also showed small cracks around the hardness impression. But the cracks presented in this sample are smaller and are at the edge of the print. As mentioned, these cracks or fractures are stress raisers and can intensify the wear rate of these paints.



(e)

Figure 6: Hardness impression after the penetration test: a) sample A, b) sample B, c) sample C, d) sample D and e) sample E.

The developed methodology proved to be satisfactory for evaluating the resistance of antifouling coatings.

The combination of wear and penetration tests showed that a coating can be wear resistant but suffer severe damage from sharp contact. This damage could change the paint behavior during the wear test.

The choice of a suitable coating must take into account several factors to actually have a long lifespan and protect the surface.

4. CONCLUSIONS

Ships have a large hull surface that must be protected from fouling and corrosion. The cost of surface maintenance can be minimized by selecting paints that will have a long life under the most diverse contact conditions.

The methodology allowed to evaluate and classify the selected antifouling coatings according to the area removal rate. Coating B had the lowest wear rate, followed by coating C. Sample A and E had the worst results. It was also noted that paints B and A were the only evaluated samples that did not expose the substrate under the test conditions.

However, paint B presented, in the penetration tests, a fracture in the coating indicating a low resistance to concentrated stresses. The occurrence of fractures can cause an acceleration of wear as the fracture can be a stress concentrating point.

5. ACKNOWLEDGEMENTS

The authors would like to thank the UFOP and Institute of Technology Vale (ITV) for providing the samples.

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