CORROSIVE PROPERTIES OF MULTI -GROOVE PADS HARDFACING WITH THE MIG METHOD

Paulina WOŹNIAK, Robert STAROSTA

Gdynia Maritime University, The Faculty of Marine Engineering, Gdynia, Poland, EU
p.wozniak@wm.am.gdynia.pl, starosta@am.gdynia.pl

Abstract

The article presents the results of corrosion tests of multi-groove pads made with the MIG method on a C45E steel substrate. The process of welding the multi-groove pads was carried out with constant parameters of the pad-welding process (i.e. current intensity, arc voltage, pad-welding speed). The results of previous tests allowed determine the optimal process parameters at which we obtain the smallest share of the base material in the padding. The pad-welding process was carried out at a current of 60 A and a wire feed speed of 2.5 mm / min. With these parameters the value of the share of the base material in the slab is the smallest and amounts to 1.7 [-]. The samples were subjected to corrosion tests in two environments (3.5 % sodium chloride solution and 0.001 sulfuric acid solution). The assessment of corrosive properties was made on the basis of constant current measurements (potentio-dynamic method). On the basis of the research, the influence of the corrosive environment on the properties of corrosion properties of paddings was demonstrated.

Keywords: Corrosion, sea water, optimization, hardfacing

## 1.	INTRODUCTION

The wear of machine components takes place in all industries. Some parts stop functioning only because of lesser damage. Using the padding technique, it is possible to regenerate machine parts or improve the surface properties such as resistance to abrasion, corrosion and aging [1]. The process of regeneration with the use of padwelding can be carried out using the same equipment that we use for welding. Additional metals and their alloys with the required properties in the form of wire, wire with powder, powder or rod are selected for the additive, respectively. In order to ensure optimal technological and economic conditions, one should strive while ensuring high efficiency of the surfacing and a small share of the base metal in the padding. The surfacing process should be carried out using pre-heating in order to evaporate the moisture and reduce the porosity of the pad [2].

The action of aggressive, electrochemical interaction of sea / outboard water also affects the deterioration of working conditions and the destruction of machine components. Corrosion activity of seawater depends on its salinity, chemical composition and temperature [3]. Corrosion protection of marine marine structures is achieved through the appropriate selection of materials with increased corrosion resistance and protective coatings. Corrosion of metals as a result of constant contact with sea water is of electrochemical nature.

The purpose of the work is to check the suitability of surfacing in the fight against corrosion in seawater. Padwelding was chosen due to the continuous development of welding techniques and their widespread use in marine constructions. Additionally, thanks to padding, we can apply additional material other than native material, which is not possible in any application of additional coatings. The subject of the research is a sample of C45E steel, on which solid stainless steel wire was applied. Napoina was made by semiautomatic welding method. The purpose of the surfacing was to increase the corrosion resistance, the strength of the material with the least amount of substrate material. After completion of the surfacing and preparation, the sample was subjected to corrosion tests. The purpose of the corrosion tests was to check the corrosion resistance of the pad. For this purpose, tests were carried out in two corrosive environments: sulfuric acid and seawater. The constant current method was used for the tests. The corrosion resistance of materials has been evaluated by testing using an impedance spectroscope.

The problem of corrosion in the marine environment is commonly described and whipping in literature, Polish and foreign language articles. Charchalis [4] reports that the application of additional coatings reduces the value of the corrosion current density and increases the corrosion potential. The actual course of corrosion processes depends to a large extent on the additional material and the substrate material as well as the environment. Adamiec [5] showed a negative influence of the presence of iron on the padding surface. The formation of Fe_3O_4 oxide deteriorates the resistance of welders to corrosion and erosion. Krzysztof [6] in their research proved that welded, the smallest stainless steel sheet used in the tests undergoes the smallest corrosion damage and shows the highest resistance to corrosion in the spore 3.5 % of sea salt.

2.   RESEARCH METHODOLOGY

In the previous studies, the influence of particular welding parameters on the value of relative errors scattering was analyzed using multiple variance analysis. The purpose of the quantitative assessment of the influence of arc welding parameters, i.e. the current I intensity and the v_l wire feed rate on the content of the substrate in the padding (CSM). A randomized, orthogonal plan of the experiment was taken into account, taking into account the trivalence of independent variables, predicting the performance of 9 experiments with five repetitions. The selection of the current during welding of the C45E steel with the additional material CastoMag 4554S was related to the short-circuit mode of transferring the liquid metal. Taking into account the current values changed in the range of 60 ÷ 90 A and the wire feeding speed of 1.5 ÷ 2.5 m / min, a plan of experiments was generated using the STATISTICA statistical program. On the basis of statistical analysis, it was found that the smallest CSM was obtained with the parameters: the padding process is carried out using the following parameters of the technological process I = 60 A, v_l = 2.5 m / min [7]. The samples for testing were made of a C45E flat bar with a thickness of 6 mm. Solid CastoMag solid wire, factory marked CastoMag4554S, was used for padwelding. The chemical composition according to the manufacturer contains chromium. nickel and manganese. The diameter of the wire is 1.2 mm. The samples were subjected to blasting or preheated to 100 ˚C. Then multi-groove pad were made. The welding process was carried out using the MIG method. The welding was carried out with the following parameters: arc voltage within 20 V, electrode wire outlet length 15 mm, pivot angle of the wire pushing, left-to-right padwelding direction, polarity on the positive wire, shielding gas flow rate 16 l / min. The shielding gas was a mixture of 82 % argon and 18% carbon dioxide. Current I = 60 A. Wire feed speed v_l = 2.5 m / min and padwelding speed 2 mm / s. The MIG Mig c340 PRO MIG welder from ESAB was used to make the pads.

In order to assess the corrosion properties, a direct-current electrochemical method - polarization - was used. This is a classic method. well-known and widely used. The measurement speed is significant compared to other test methods. Thanks to electrochemical polarization tests we are able to estimate the instantaneous rate of corrosion. as well as determine the nature of partial processes. [4]

$$j = j_{corr} \left[\left(1 - \frac{j_a}{j_{da}}\right) exp \left(\frac{2.3(E - E_{corr})}{b_a}\right) - \left(1 - \left|\frac{j_k}{j_{dk}}\right|\right) exp \left(\frac{-2.3(E - E_{corr})}{b_k}\right) \right] \tag{1}$$

where:

      j - polarization current density (mA / cm^2)

      j_{corr} - corrosion current density (mA / cm^2)

      E - polarization potential (mV)

      E_{corr} - corrosion potential (mV)

      b_a - anode ratio Tafel (mV)

      b_k - cathode Tafel (mV)

      j_a - density of the partial current of the anodic reaction (mA / cm^2)

      j_k - density of the partial current of the cathode reaction (A / cm^2)

      j_{da} - density of the anodic limit current (diffusive) (A / cm^2)

      j_{dk} - density of the anodic boundary current (diffusive) (mA / cm^2)

Polarization measurement was performed in a three-electrode system. A 1.2 cm² de-acetone sample, a platinum polarizing electrode and a reference electrode (calomel saturated) were placed in a vessel containing 500 ml of 3.5 % NaCl solution (substitute sea water) at ambient temperature. Before taking measurements, the samples were subjected to one hour of exposure in the electrolyte. During the measurement, the electrolyte was mixed all the time. The polarization tests were performed with the ATLAS 0531 instrument. By registering the polarization curves j = f (E) in the range of ± 500 mV from the corrosive potential. The potential speed in all cases was 10 mV / min. In order to determine the values of values characterizing the corrosion properties of the tested material, the computer program "Elfit - corrosion polarization data fitting program" was used, which counts parameters from equation (1). To assess the effect of padding on corrosion resistance of steel the calculated values of corrosion current density and corrosive potential were used.

3.   RESEARCH RESULTS

Figures 1 and **2** show exemplary polarization diagrams of welded pads of CastoMag4554S material obtained on a substrate made of C45E steel. Analysis of the polarization graphs showed that in the environment of the sulfuric acid solution, corrosion proceeds under activation control, and in the environment of 3.5 % NaCl solution, the diffusion constraints accompanying the reduction reactions were observed. **Table 1** shows current density values j_{corr} corrosion and the corrosion potential E_{corr} calculated from individual measurements for both corrosive environments. The obtained results were subjected to basic statistical analysis.
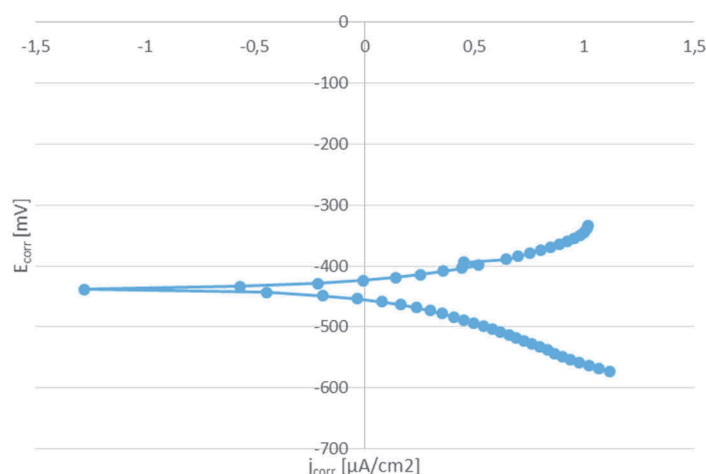

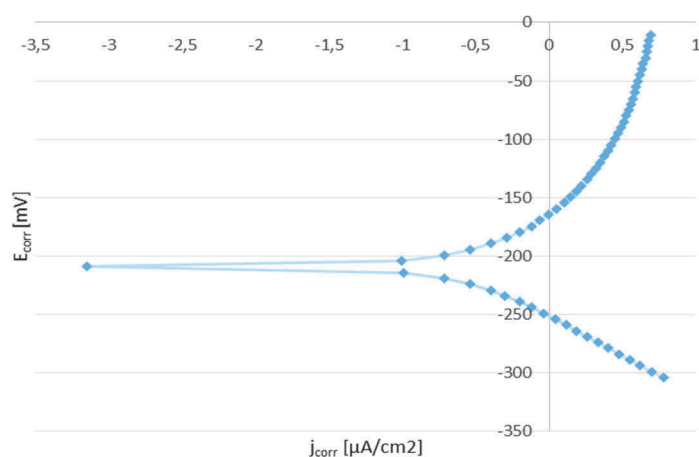**Figure 1** Polarization curves of the tested samples in the sea water replacement environment

Figure 2 Polarization curves of the tested samples in an environment of 0.01 M sulfuric acid

Table 1 Characteristic of examined materials corrosion resistance by using polarization curves method

No	Environment	Ecorr [mV]	Jcorr [µA / cm^2]	Environment	Ecorr [mV]	Jcorr [µA / cm^2]
1		-128.333	19.572		-168.847	8.90804
2		-318.809	8.32724		-290.742	35.1522
3		-197.48	10.3546		-247.776	8.90804
4		-241.809	37.4088		-437.589	1.29554
5	H_2SO_4	-461.472	9.0891	NaCl	-263.581	8.75307
6		-102.713	8.57044		-220.999	13.5525
7		-354.22	8.4232		-320.333	10.322
8		-283.22	9.3211		-400.233	9.145
9		-255.66	12.234		-370.322	11.333

From the results of the statistical parameters presented in **Table 2**, a similar value of the standard deviation and the average value of the analyzed corrosion process parameter (j$_{corr}$) in all applied electrolytes were observed. For example, for tests carried out in a sea-water replacement environment, the mean value j$_{corr}$ = 11.8 µA / cm^2, and the standard deviation value was 9.4 µA / cm^2. The relatively high value of the deviation is related to the large spread of the obtained measurement results. The range is set to 34 mA / cm^2. The high standard deviation and range can be the result of the appearance of indeterminate fatal errors during polarity measurements. To verify the hypothesis about the possibility of fatal errors, a statistical Grubbs test was used. The analysis was carried out at the assumed significance level of a = 0.05.

Table 2 The results of basic statistical analysis for the values of corrosive current density

Variables	N important	Average	Confidence -95,000%	Confidence 95,000	Distance	Standard deviation	Standard error
0.01 M H_2SO_4	9	13.55	6.212	20.89	29.00	9.55	3.18
3.5 % NaCl	9	11.77	4.579	18.97	34.00	9.36	3.12

Table 3 Results of the Grubbs test for the a) value of corrosive current in the environment of 0.01 M sulfuric acid, b) corrosive current value in the seawater substitute environment

No. a)	VALUE	Test results (Z)	SIGNIFICANT OUTLIER	No. b)	VALUE	Test results (Z)	SIGNIFICANT OUTLIER
1	19.572	0.613		1	8.908	0.324	
2	8.327	0.561		2	35.152	2.493	
3	10.354	0.349		3	8.908	0.324	
4	37.409	2.476	P<0.05	4	1.295	1.142	P<0.05
5	9.089	2.476		5	8.753	0.341	
6	8.570	0.536		6	13.552	0.174	
7	8.423	0.551		7	10.322	0.173	
8	9.321	0.457		8	9.145	0.299	
9	12.234	0.153		9	11.333	0.064	

The critical value Z for the Grubbs test was 2.22. The results of the statistical analysis were presented in **Tables 3, 4**. The obtained results of the analysis allow for the assumed level of significance (a = 0.05) for the statement that the values of corrosion current density j$_{corr}$ = 37.409 mV / cm^2 for 0.01 M sulfuric acid solution

and j$_{corr}$ = 35.152 mV / cm^2 for the sea water replacement environment are affected by the error thick measurements. Therefore, the basic statistical analysis was repeated, omitting the value of the corrosion current density, which were burdened with a thick measurement error, and its results are presented in **Table 3** and in **Figure 3**.
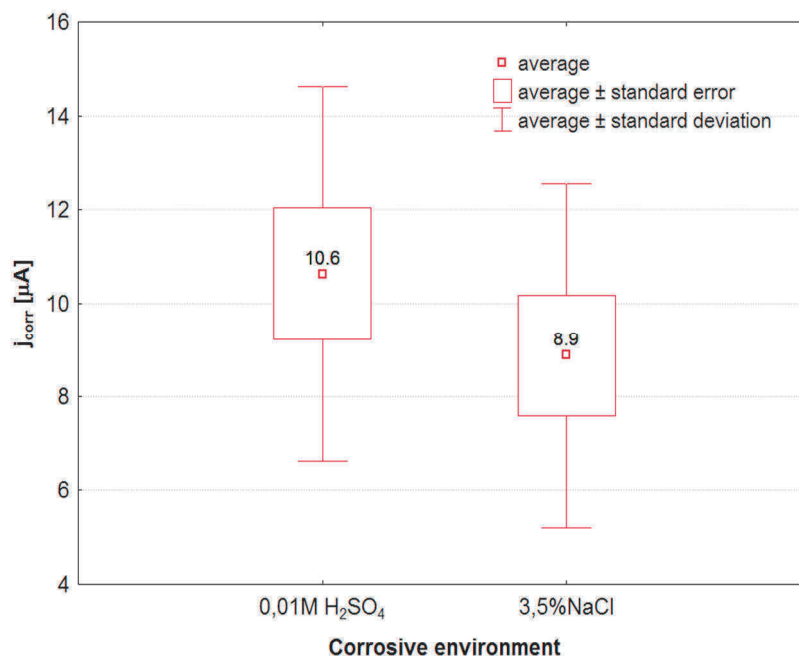

Figure 3 The influence of the environment on the density of the corrosive current

The test result for the corrosion potential parameter did not show the possibility of making a gross error, so no value needs to be removed in order to reduce the spread of results. The results of the basic statistical analysis for corrosion potential are shown in **Figure 4**.
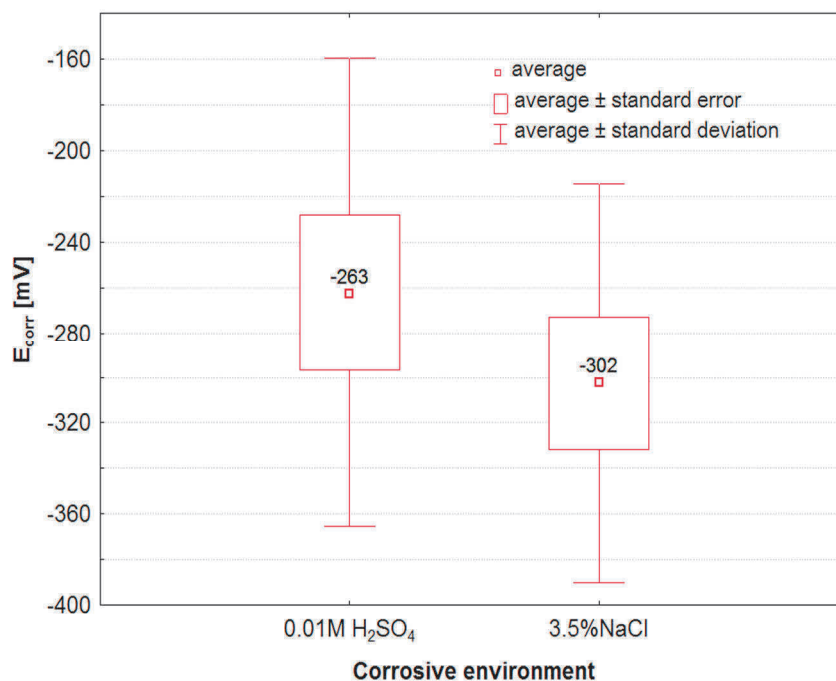

Figure 4 The impact of the environment on the corrosion potential

Table 4 Wald test results

Variables	Mean 0.01M H$_2$SO$_4$	Mean 3.5% NaCl	Z	Level p H$_2$SO$_4$	Level p NaCl
j$_{corr}$ [µA]	10.625	8.875	0.518	0.605	0.796
E$_{corr}$ [µA]	-262.667	-302.333	1.458	0.145	0.224

Table 5 Kołmogorow - Smirnow test results

Variables	maximum negative difference	maximum positive difference	Level p	Mean 0.01M H$_2$SO$_4$	Mean 3.5 % NaCl
j$_{corr}$ [µA]	0.00	0.125	p> .10	10.625	8.875
E$_{corr}$ [µA]	-0.111	0.333	p> .10	-262.667	-302.333

Standard deviation values in the case of current density and corrosion potential analysis are very similar for both environments. In order to check the significance of differences in the corrosion parameters of two independent variables, three nonparametric tests were performed: Walda - Wolfowitz, Kolmogorow - Smirnow and U Mann - Whitney. The test results for both parameters are presented in **Tables 4 - 6**.

Table 6 Mann - Whitney test results

Variables	Mean 0.01M H$_2$SO$_4$	Mean 3.5 % NaCl	U	Level p H$_2$SO$_4$	Level p NaCl
j$_{corr}$ [µA]	70.000	66.000	30.000	0.834	0.829
E$_{corr}$ [µA]	96.000	75.000	30.000	0.354	0.354

The results of significance tests of differences for two independent variables showed that the value of the corrosion process parameters has no basis for rejecting hypothesis 0, which states that there are no differences between the studied environments. Therefore, with the probability of 95 %, it can be concluded that the corrosion process of paddings made of CastoMag 455S wire in the tested environments proceeds with the same speed.

4.   CONCLUSION

The article is the introduction to a series of corrosion tests for the sea water environment and its impact on changes on the surface of machine parts and equipment. When measuring paddings made of CastoMag 4555S wire on a C45E steel substrate obtained by MIG method with parameters: 60 A padwelding current and 2.5 m / min wire feed speed. Corrosion current density in the sea water replacement environment is 8.9 µA and for 0.01 M sulfuric acid 10.6 µA. Corrosion potential for the sea water environment is -302 mV for 0.01 M sulfuric acid -263 mV. The statistical analysis carried out showed that the differences are statistically not significant, so it can be assumed that in both environments the corrosion process will proceed at a similar pace.

REFERENCES

[1]   WINCZEK, J. Modelling of heat affected zone in cylindrical steel elements surfaced by welding. *Procedia Engineering, 2012,v*Vol. 36, pp. 1514 - 1528.

[2]   WINCZEK, J. Modeling of heat affected zone in multipass GMAW suffacing S235 steel element. *Procedia Engineering*, 2016, vol. 136, pp. 108 - 113.

[3]   LOPEZ-ORTEGA, A., BAYON, R., ARANA, J. Evaluation of protective coatings for offshore applications. Corrosion and tribocorrosion behavior in synthetic seawater. *Surface and Coatings Technology*, 2018, vol. 349, pp. 1083 - 1097.

[4]   CHARCHALIS, A., STAROSTA, R. Konstytuowanie eksploatacyjne warstwy wierzchniej w procesie tarcia technicznie suchego. *Problemy Eksploatacji*, 1998, no. 2, pp. 5 - 36.

[5]   FUKAYA, Y., WATANABE, Y. Characterization and prediction of carbon steel corrosion in diluted seawater containing pentaborate. *Journal of Nuclear Materials*, 2018, vol. 498, pp. 159 - 168.

[6]   KRAMAR, V., *DUSHKO, V., RODKINA, A., AZAIETS, A.* Influence of stress-corrosion fractures on potential of ship - building metals in the sea water. *Procedia Engineering*, 2015, vol. 100, pp. 1068 - 1074.

[7]   WOŹNIAK, P., STAROSTA, R. Optymalizacja parametrów napawania stali C45E drutem CastoMag 4554S Metodą Taguchi. *Zeszyty Naukowe Akademi Morskiej w Gdynii*, 2017, vol. 100, pp. 187 - 199.