CORROSION RESISTANCE OF FILM VENTURESHIELD VS ™ 7510 E TO THE PRESENCE OF DISINFECTANTS AND BODILY FLUIDS

WAŚ-SOLIPIWO Joanna[1], HAJDUGA Maciej[2], WĘGRZYNKIEWICZ Sylwia[3]

[1] *Research and Development Institute of Automotive Industry BOSMAL Sp. z o.o., Bielsko-Biała, Poland, EU*
[2] *Academy of Technology and Humanities, Bielsko-Biała, Poland, EU*
[3] *BELOS - PLP S.A., Bielsko-Biała, Poland, EU*

Abstract

The study presents the results of the corrosion resistance research of DC01 steel, protected by VentureShield™ VS 7510 E film. The assessment of corrosion resistance of the examined material was conducted by using linear polarization method, according to the EN ISO 10271:2012 standard. Various corrosion substances were used, i.e. disinfectants (based on ethanol) and bodily fluids. The data was referred to the research results of DC01 steel surface corrosion not protected by film.

The results confirm that VentureShield ™ VS 7510 E film applied as a protection coating provides good protection against corrosion, in the contact with disinfectants and bodily fluids and may be used for the protection of ambulances interior, as well as in hospital environment.

Keywords: Protective film, corrosion resistance, potentiodynamic method

1. INTRODUCTION

The development of modern materials science in the field of protective coatings is well advanced. We are constantly looking for better solutions, especially in the medical field. Steel parts applied in hospital conditions are protected against corrosion by metallic and varnish coatings. Some elements of hospital accessories are protected by the following coatings: Ni, Cr, Cu, Zn as well as CVD and PVD coatings. The exploitation of constructions and medical equipment in severe conditions poses a threat of damaging protective coatings. We may observe a significant decrease in the corrosion resistance of the used protective coating due to long-lasting usage, which leads to corrosion occurrence. In the next step, bacterial cells accumulate and develop. It poses a danger for the patient being at risk of an infection, as long as the bacterial flora remains present on the surface of hospital, diagnostic or rehabilitation equipment [1-5].

The authors conducted the research [6, 7] to find out the effectiveness of using protective films on steel in the medical environment. It is a quite recent solution, frequent in the automotive industry. Films are applied on the cars elements, especially threatened by mechanical damage, i.e. bumpers, inner wheel arches, doors. Films are wear and scratch resistant, and are not damaged by chemical factors (roads salinisation). Their use allows for the increase of the functionality of protected surfaces and it aids to retain esthetical appearance for a long period of time.

The authors has decided to extend the range of the research and to concentrate on the assessment of the properties of protective film in the corrosive environments, i.e. Ringer's solution, artificial saliva and blood substitute. The aim of this paper is a comparison of corrosion resistance to the presence of disinfectants and bodily fluids.

2. TESTED MATERIAL

The research object is still an ambulance constructed on the HONKER chassis (**Figure 1**) used in special conditions.

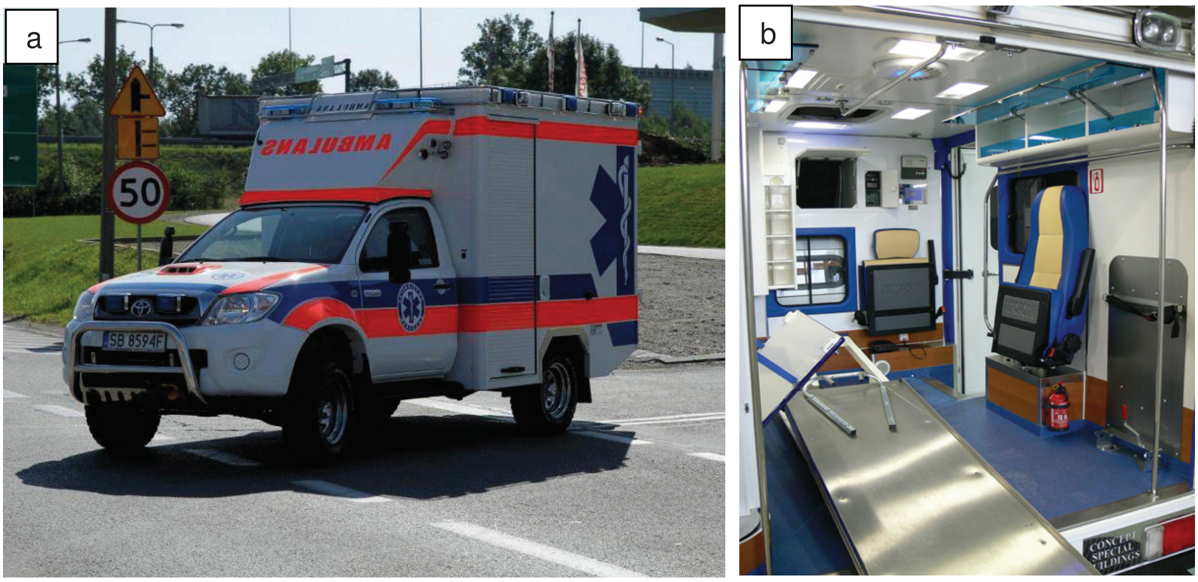

Figure 1 The view of military ambulance a - outside view of Honker; b - inside survival equipment

2.1. Sample preparation

The DC01 steel was selected for the research in form of cold-rolled sheet-metal, size 1000 x 2000 mm, and thickness 0.75 mm. The chemical composition of the researched steel according to EN 10130:2009 and the results of chemical analysis was as follows: 0.007 %C; 0.02 %P; 0.016 %S; 0.49 %Mn; 0.034 % Al; 0.060 %Si; 0.056 %Cu; 0.013 %Cr; 0.032 %Ni.

Samples of 15 mm diameter were cut out of accidentally selected areas of sheet metal. Samples were grinded by discs and then polished. Then, thermoplastic polyurethane film of 14 mm diameter was applied. Acrylic adhesive was used. Isopropyl alcohol was used as the solvent, and gelatin as a thickener. The initial thickness of the film and adhesive was 210 µm, specific weight 240 g/m^2, tensile strength and elongation 5400 N/cm^2, 460%.

2.2. The research material division

The researched material was divided into five groups, depending on the type of corrosive environment, which may be seen in **Table 1**.

Table 1 Marking medium corrosion for the research

Corrosive environment		Group	Concentration or the qualitative and quantitative composition
DISINFECTANTS	C_2H_5OH (etanol)	**D1**	24 %, pH 6.4; 48 %, pH 7.7; 96 %, pH 9.1
	„Domestos“	**D2**	50 % (2.25 g NaOCl / 100 g), pH 13.1 100 % (4.5 g NaOCl / 100 g), pH 13.3
BODILY FLUIDS	Ringer's solution	**B1**	8.6 g/l NaCl, 0.3 g/l KCl, 0.33 g/l $CaCl_2$, pH 6.8
	Artificial saliva	**B2**	0.2 g/l K_2HPO_4, 0.26 g/l Na_2HPO_4, 0.33 g/l KSCN, 1.5 g/l $NaHCO_3$, 0.7 g/l NaCl, 0.13 g/l $(NH_2)_2CO$, 1.2 g/l KCl, pH 8.5
	Blood substitute (SBF 1)	**B3**	8.0 g/l NaCl, 0.35 g/l $NaHCO_3$, 0.22 g/l KCl g/l, 0.23 g/l K_2HPO_4 $3H_2O$, 0.31 g/l $MgCl_2$ $6H_2O$, 0.28 g/l $CaCl_2$, 0.07 g/l Na_2SO_4, 6.06 g/l $(CH_2OH)_3CNH_2$, 1 mol HCl. pH 7.25

3. METHOD OF INVESTIGATION AND RESULTS ANALYSIS

3.1. The surface topography assessment

In order to assess the surface topography, Perthometer Concept (MAHR) profilometer, with 3D equipment and software, was used. The measurement was conducted in a few, accidentally chosen areas. The analysis was focused on the area of 1.6 x 1.6 mm. The distance between the measurement points was 0.5 µm, the number of profiles was 81, and the distance between them was 20 µm. The topography of the surface of the film was presented in **Figure 2**.

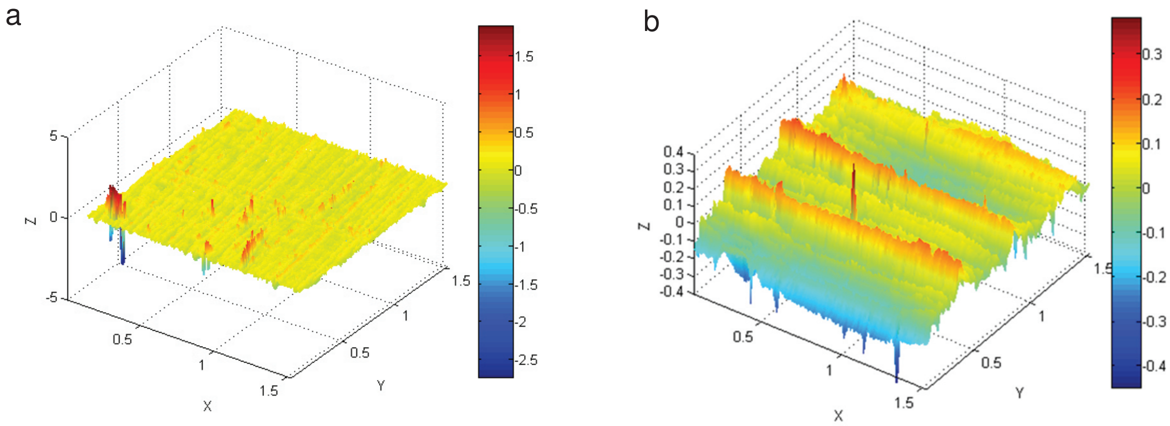

Figure 2 The topography of selected sample area a - steel after grinding and polishing, b - film

3.2. The corrosion resistance evaluation

The electrochemical research of corrosion resistance was based on potentiodynamic method in corrosive solutions oxygenated in a result of free contact with the air (**Table 2**), in 37 °C. The research was conducted by use of a measurement system consisting in the Autolab PGSTAT302N potentiostat, no. AUT83628 produced by ECO CHEMIE B.V. company, which cooperates with the Nowa 1.7 software, by Metrohm Autolab B.V.

The samples were conditioned in the examined environment for about 1 hour (in case of the film) or washed by acetone (in case of DC01 steel) and conditioned in the examined environment for 1 hour. After that they were mounted to the brass pin, inserted into teflon holder, sealed by silicon rubber. The examined electrode prepared in this way was placed in the side stub pipe of the electrochemical cell (400 cm^3 capacity), equipped with water coating.

The system was connected to the Julabo ED 5 thermostat, which ensures the precision of regulation by ± 0.1°C. A probe, together with a reference electrode, were placed in a lid. Its role was fulfilled by calomel electrode (NEK, Hg / Hg_2Cl_2(s) / KCl(nas.)) of the +244 mV potential compared to NEW in temperature 25 °C with Haber-Luggin capillary at the end. The capillary end was situated about 1 mm away from the researched electrode surface - the sample. Before starting the research, the accuracy of potentiostat work was tested by use of a calibration cell and Diagnostics 1.7 program, which checked if the device worked properly.

The research was conducted by use of linear polarization method with potentials ranging from -0.1 V to 0.1 V, with the current range 1 mA and scanning rate 0.001 V/s, according to the EN ISO 10271:2012 standard.

By comparing the experimental curves with the curves described by the Tafel equation the following parameters were determined: the corrosion current density j_{kor} [nA/cm^2], and the following values were calculated: the corrosion potential E_{kor} [mV], measured from the minimum on the polarization curve, the corrosion rate V_p [mm/year] and the polarization resistance R_p [MΩ/cm²]. Furthermore, the stationary potential OCP (equilibrium potential) as potential change over time by potentiostatic method was determined.

All parameters were established compared to steel, for which the electrochemical equivalent was 27.925 g/mol, density 7.86 g/cm². The area of the examined sample equalled 0.385 cm².

The results, which were the average of three measurements, are compared in **Tables 2 and 3**.

Table 2 The results of the measurement of corrosion resistance of steel covered with the film in corrosion solutions (**Table 1**)

Established parametres	DISINFECTANTS					BODILY FLUIDS		
	D1			D2		B1	B2	B3
	24%	48%	96%	D50%	D100%			
OCP	-0.266	0.082	0.093	-0.382	-0.298	-0.157	-0.150	-0.152
E_{kor} [mV]	-334.5	26.4	118.9	-422.4	-332.6	-184.1	-163.1	-170.4
j_{kor} [nA/cm²]	1.105	0.214	1.301	194.17	83.885	0.225	4.530	0.275
V_p [mm/rok]	1.30E-05	2.50E-07	1.50E-05	2.20E-03	9.70E-04	2.62E-06	6.60E-06	3.19E-06
R_p [MΩ/cm²]	243.1	307.2	89.5	2.2	300.3	99.8	62.8	99.5

Table 3 The results of the measurement of corrosion resistance of DC01 steel in corrosion solutions (**Table 1**)

Established parametres	DISINFECTANTS		BODILY FLUIDS		
	D1 24%	D2 50%	B1	B2	B3
OCP	-0.095	-0.264	-0.252	-0.201	-0.258
E_{kor} [mV]	-119.3	-258.4	-272.6	-227.1	-300.0
j_{kor} [µA/cm²]	0.301	8.884	6.843	11.328	16.667
V_p [mm/rok]	0.003	0.103	0.079	0.132	0.206
R_p [MΩ/cm²]	1.354	0.093	0.675	1.094	0.967

4. THE SUMMARY AND FINDINGS

The value of open circuit potential OCP for the DC01 steel covered by film, depending on the corrosive environment, equals from 0.093 to -0.382. The most positive OCP value was achieved in 96% ethanol solution. This provided evidence that film coating on steel is stable and fulfils its role of protecting metal from corrosion. It may be ascribed to the fact that film becomes softer in the ethanol environment, and its plasticity improves the adhesion to steel, increasing the protective properties. The lowest OCP value was observed in 50% Domestos solution. In such solutions, the most intensive corrosion occurrence may be expected. The similar values of OCP for bodily liquids were observed. It may be stated that, for all the physiological solutions the examined film completely the protective properties.

The corrosion potential E_{kor}, depending on the environment, ranged from 118.9 to -422.4 mV. The highest value of corrosion potential was obtained for 96% ethanol solution. It may be assumed that corrosion susceptibility decreases in such environment. The lowest values were observed in 50% Domestos solution. For bodily liquids similar results are obtained. The similar values of the corrosion potential for all bodily liquids were obtained. It may be assumed that, in the physiological solutions steel protected by film characterize corrosion resistance.

The density of corrosion current j_{kor} varies from 194.17 to 0.214 nA/cm². The highest density was reported in 50% Domestos solution, the lowest in 48% ethanol solution. According to these values it may be supposed that the most aggressive corrosion environment is 50% Domestos solution. It causes film damage and surface corrosion. The 48% ethanol solution is the least corrosive for steel covered with a film. For bodily liquids the density of corrosion current varies from 0.225 to 4.530 nA/cm^2 were obtained. The highest density was reported in artificial saliva solution, the lowest in Ringer's solution. According to these values it may be supposed that the most aggressive corrosion environment is artificial saliva solution.

As a result of comparison of the results of corrosion rate V_p in terms of values from $2.2 \cdot 10^{-3}$ to $2.5 \cdot 10^{-7}$ mm/year. It has been proved again that corrosion processes progress the fastest in 50% Domestos solution, and the slowest in 48% ethanol solution. Corrosion rate V_p in terms of values from $2.62 \cdot 10^{-6}$ to $6.6 \cdot 10^{-6}$ mm/year were observed. The lowest value was obtained in Ringer's solution, and the highest in artificial saliva solution. However, due to the low value of corrosion rate, it may be again concluded that the examined film is protected the steel from the corrosive environment of physiological fluids.

The achieved values of polarization resistance R_p ranged from 307.2 to 2.2 MΩ/cm^2. The highest corrosion resistance was observed in 48% ethanol solution, and the lowest in 50% Domestos solution. In bodily liquids the achieved values of polarisation resistance R_p ranged from 62.8 to 99.8 MΩ/cm^2. The highest value of polarization resistance was observed in Ringer's solution, and the lowest in artificial saliva solution. All this means, that the steel samples covered by film are characterized by the highest corrosion resistance in Ringer's solution, and the lowest in artificial saliva solution.

Comparing the parameters values (**Tables 2 and 3**) for unprotected and protected steel it has been stated, that the examined film protects steel DC01 against corrosion in disinfectants and bodily fluids.

To summarize the above discussion of the values obtained during corrosion research of steel covered by film in all analyzed disinfectants and bodily fluids, it may be concluded that the examined film effectively protects the steel grade DC01 as the base material of medical equipment and ambulances interior. The type of the bodily fluids insignificantly influences on the protection functions of films. However the corrosion resistance of the film in body fluids is higher than in disinfectants.

To sum up, it may be concluded that thermoplastic polyurethane VentureShield™ VS 7510 E film applied as a protection coating on the DC01 steel significantly delays the initiation and flow of corrosion processes. The examined film may be utilized as the DC01 steel protection inside ambulances and in the hospital environment.

VentureShield™ VS 7510 E film applied as a protection coating on the DC01 steel is a relatively good protection against corrosion that occurs under physiological fluids. Film significantly delays the initiation and flow of corrosion processes.

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