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ANALYSIS OF PLATED LAYER'S EFFECTS ON THE STRUCTURE RESISTANCE TO CORROSION

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This paper presents the laboratory testing of protective effects that the plated layer had on the structure resistance to corrosion by using the weighing method, i.e. the method of mass loss. The described procedure refers to preparation of samples, their exposure to aggressive atmosphere of the salt chamber and analysis of obtained results. According to the properties of the base material and its reduced stability in the experimental conditions, it is confirmed that the use of plated layer was required to improve the structure resistance to corrosion and to protect the base material.

Keywords: corrosion, weighing method, plated layer, SS 304L, salt chamber/NaCl

INTRODUCTION

Exploitation properties and service time of any structure depend greatly on the resistance to corrosion of the material from which it is made. In order to ensure structure stability from the viewpoint of its dimensional and demanded properties, it is necessary to prevent its deterioration and loss of mass caused by various corrosion mechanisms [1]. Occurrences of corrosion mechanisms are known as spontaneous heterogeneous chemical processes that involve the construction material and the gaseous or liquid environmental component to form a solid, dissolved or gaseous corrosion product [2]. In order to prevent such mechanism, it is necessary to apply appropriate surface protection technology on the base material, if it does not have good resistance to corrosion. Plating is one of the procedures used to protect the base material and the entire structure by coating them with the corrosion-resistant material [3].

Plating refers to the application of metal coating by plastic deformation, i.e. by applying more resistant metals on the surface by means of high pressures that cause the metal coating flow. Occurrence of the surface flow is not a common case. Coating can be carried out in different ways, such as warm rolling, electric arc welding under dust or explosion [4]. Samples used in this experiment were made by plating by electric explosion. In order to examine the protective properties of the plated layer, samples were exposed to the corrosive medium and then tested in the laboratory conditions.

EXPERIMENTAL PROCEDURE

Samples of dimensions 60 x 13 x 13 mm were used to test and analyze the effects of the plated layer on the resistance of the structure to corrosion (Figure 1).

Experimental samples were composed of the 10 mm-thick base material SA 516 Gr. 70 and of the 3 mm-thick plated layer made of the SS 304 L material. Chemical composition of each material is presented in the Tables 1 and 2.

Table 1 **Chemical composition of the base material Sa 516 Gr. 70 / wt. % [5]**

C	Mn	P	Si	S
0,28	0,79-1,3	0,035	0,13-0,45	0,035

Table 2 **Chemical composition of the plated layer made of SS 304 L material / wt. % [6]**

C	Cr	Mn	Ni	Si	N
≤0,03	18-20	≤2	8-12	≤0,75	≤0,1

There were 8 samples cut out from the plate of the above-stated dimensions. Samples were mechanically cleansed with wet sandpaper to remove possible corrosion products and to provide samples of the same initial condition for further testing in the salt chamber.

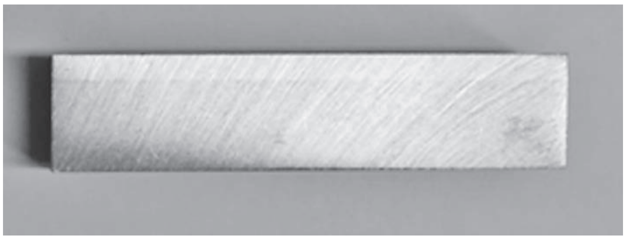

Figure 1 Experimental sample

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Testing in the salt chamber refers to provision of desired atmosphere for accelerated formation of corrosion. In this experiment, the testing provided the conditions of coastal atmosphere obtained by spraying the NaCl solution inside the chamber, thus creating an aggressive nebula [7].

Salt chamber parameters and the atmospheric conditions inside the chamber are in line with the ISO 9227 standard, as presented in the Table 3.

Table 3 **Salt chamber parameters applied in the experiment [7]**

Temperature / °C	Concentration of NaCl / %	pH value
35 ± 2	5	6,5 – 7,2

There were 6 out of 8 samples exposed to atmospheric conditions in the salt chamber. Two samples were kept in the initial state to serve as a reference for comparison of results. Tested 6 samples were divided into three groups that differed in duration of exposure to the aggressive atmosphere of the chamber. Each group contained two samples. The first group of samples were kept in the chamber for 48 hours, the second group for 96 hours, and the third group for168 hours. The increase in the number of hours of exposure aimed to prove a continuous, almost linear trend of material corroding that resulted in mass loss of tested samples. The values of the test duration are in accordance with the recommended values according to the ISO 9227 standard. Since the analysis is based on the laboratory method of weighing, i.e. of mass loss, it was necessary to weigh the samples prior to exposure to the aggressive atmosphere. Weighing was carried out on the Scaltec SPB32 laboratory scale with a measuring range of up to 120 grams and a precision of four decimal places.

Weighed samples were placed in the salt chamber and taken out after each treatment, according to the determined time intervals. Samples were photographed after being removed from the chamber. The following figures show the conditions of samples after the accelerated testing in the salt chamber.

In addition to defining duration of exposing samples to aggressive atmosphere of the salt chamber and weighing of the samples, the experiment required determination of sample masses after the treatment and after removing of the corrosion products that were formed during exposure. Removal of corrosive products was performed by mechanical cleaning of the sample surface by using soft wire brushes under water jet, and the results of weighing such cleaned samples, as well as the data about the total mass losses are overviewed in the Table 4. The mass loss for each sample refers to the difference in masses obtained prior to the salt chamber exposure and after the treatment.

After cleaning and weighing of samples, they were also visually observed to confirm that the total mass loss referred only to the part of samples made out of the base material. This could be confirmed already at removing the samples from the salt chamber, as it was clearly visible that the line of corrosion products was the same as the line separating the base material from the more corrosion-resistant plated layer, as shown in the above Figures 2, 3 and 4. After cleaning, it was also determined that several small parts of the plated layer covered with the corrosion product did not actually corrode themselves, but this corrosion was leaking from the base material while exposure in the salt chamber.

Figure 2 Condition of the sample after 48-hour exposure in salt chamber

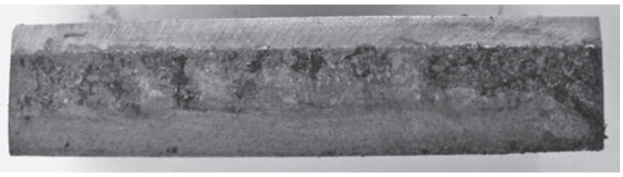

Figure 3 Condition of the sample after 96-hour exposure in salt chamber

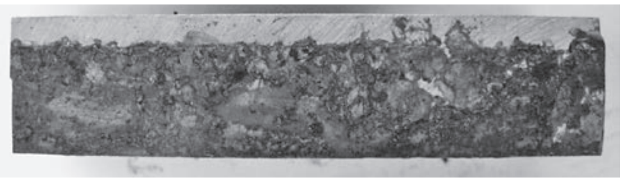

Figure 4 Condition of the sample after 168-hour exposure in salt chamber

Table 4 **Mass loss of experimental samples after exposure to aggressive atmosphere**

t / h	Sample	m_1 / g	m_2 / g	Δm / g
0	1-1	91,5194	91,5194	0,0
	1-2	84,4159	84,4159	0,0
48	1-3	83,6487	83,5444	0,1043
	1-4	85,6584	85,5474	0,111
96	1-5	92,1983	92,0081	0,1902
	1-6	87,5264	87,3126	0,2138
168	1-7	91,7637	91,4545	0,3092
	1-8	88,9763	88,6480	0,3283

When presenting mass losses in a graph that shows the dependence of mass loss on the duration of treatment, it is clear that mass loss has almost linear growth trend, Figure 5.

After calculating the mass loss for each treated sample, it was possible to calculate real average corrosion rate ($\overline{v}$) for all samples, by using the following formula [2]:

$$\overline{v} = \frac{m_1 - m_2}{s(t_2 - t_1)} = \frac{\Delta m}{s\Delta t} \tag{1}$$

where: m_1 is sample mass of sample before treatment, m_2 is sample mass after treatment, Δm id the dif-

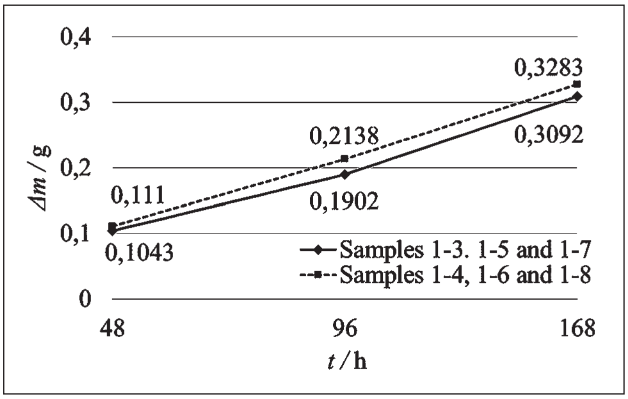

Figure 5 Mass loss (Δm / g) in dependence on duration of exposure (t / h) of samples to aggressive atmosphere

ference in mass before and after the treatment, S is initial geometric surface of exposed material, Δt is exposure duration.

When calculating initial geometric surface of material, it is important to pay attention on the results of visual inspection of the treated samples, as it proved that the corrosion product occurred on the base material, while the coating did not corrode. Therefore, the dimensions of treated samples were calculated as 60 x 13 x 10 mm, without the 3 mm plated layer.

The next step was to convert real average corrosion rate into the average rate of corrosion penetration in the material ($\overline{v}_p$), by using the following formula [2]:

$$\overline{v}_p = \frac{\Delta m}{s\rho_m \Delta t} = \frac{\overline{v}}{\rho m} \qquad (2)$$

in which it is necessary to know the density of base material ρ_m that corroded. In this case, the density of SA 516 Gr. 70 base material was 7,80 g/cm^3. The Table 5 presents calculated values of real average corrosion rate, as well as the average rate of corrosion penetration in the material.

Table 5 **Calculated values of real average corrosion rate ($\overline{v}$) and the average rate of corrosion penetration in the material ($\overline{v}_p$)**

Sample	$\overline{v}$/ g·cm^{-2}·d^{-1}	$\overline{v}_p$ / mm·a^{-1}
1-1	0	0
1-2	0	0
1-3	$1{,}7268 \cdot 10^{-5}$	0,803
1-4	$1{,}8377 \cdot 10^{-5}$	0,876
1-5	$1{,}5745 \cdot 10^{-5}$	0,73
1-6	$1{,}7699 \cdot 10^{-5}$	0,8395
1-7	$1{,}4626 \cdot 10^{-5}$	0,6935
1-8	$1{,}553 \cdot 10^{-5}$	0,73

After calculating average rate of corrosion penetration for each treated sample, it was possible to make orientation classification for the corroded base material and rank it as of its durability and usability. The classification was carried out according to the Table 6.

If considering the calculated values, it is clear that each treated sample subjected to the aggressive atmosphere had reduced durability and it could be only occasionally used as a construction material.

Table 6 **Classification of material depending on the average rate of corrosion penetration in the material [2]**

Durability of material	Usability of material	$\overline{v}_p$ / mm·a^{-1}
completely	always	< 0,001
very	mostly	0,001 - 0,01
stable	usually	0,01 - 0,1
reduced	sometimes	0,1 - 1
weak	exceptionally	1 - 10
unstable	unusable	> 10

CONCLUSION

The results obtained after analysis of effects that protective plated layer had on the resistance of structure to corrosion showed that base material was not sufficiently stable under the experimental conditions and that it required a plated layer coating to increase its corrosion resistance. The visual inspection after removing the tested samples from the salt chamber and the follow-up inspection after cleaning the samples already confirmed that entire corrosion product was formed only on the base material, while the plated layer remained intact, with no corrosion. Further investigation of the base material's resistance to corrosion performed by weighing method, i.e. by measuring of the mass loss, confirmed the previous conclusions of the visual inspection. According to the calculated values for each treated sample, being in the range from 0,1 and 1 mm·a-1 of corrosion penetration rate, the base material exhibited reduced stability in the experimental conditions. In order to preserve the material in service conditions, as tested in this experiment, it is necessary to protect it by the plated layer to ensure its dimensional stability and to assure required exploitation properties of the whole structure made out of that material.

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Note: Responsible translator; Martina Šuto, University of Osijek, Osijek, Croatia