

Evaluating the Corrosion Resistance of Multi-Element Metal Coatings

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Abstract. The paper presents evaluating the corrosion resistance of ion-plasma coatings obtained using the cathodes: Zr, Al, Cu, Al-Fe, Zn-Al, Zn-Cu-Al and the stainless steel cathode 12X18H10T. The ordered columnar structure arising from the self-organization of plasma coatings is discovered. It is stated that the corrosion resistance of the greater part of the investigated coatings is similar to the most corrosion-resistant steels. To improve the corrosion resistance of metallic coatings it is recommended to increase its surface tension. This requires using the most refractory metals as alloying additives.

INTRODUCTION

The problem of corrosion damage of oil and gas equipment parts and components is very important today. Most often, it is solved by applying corrosion resistant metallic and non-metallic coatings on the equipment parts surface by various methods.

The metallic anti-corrosion coating by plasma methods has widespread application [1-6].

The corrosion resistance of multi-element coatings obtained by an ion-plasma method is investigated in the present work.

EXPERIMENTAL TECHNIQUE

The objects under study are coatings surfaced on samples of 45 steel by an ion-plasma method in HHB - 6.6И1 vacuum plant in simultaneous sputtering of cathodes in the gaseous environment of nitrogen for 40 min when arc current $I = 80$ A, the reference voltage $U = 200$ V and the gas chamber pressure $P = 5 \times 10^{-3}$ mm Hg. The cathodes: Zr, Al, Cu, Al-Fe, Zn-Al, Zn-Cu-Al and cathodes of 12X18H10T stainless steel have been used.

Electron microscopic study was conducted on TESCAN MIRA 3 scanning electron microscope. The study was conducted at an accelerating voltage of 20 kV and the working distance of 15 mm. Nanoscale measurements were carried out on NT-206 atomic force microscope.

Corrosion resistance has been determined according to GOST 9.908 – 85.

EXPERIMENTAL RESULTS

The corrosion rate of the investigated coatings is presented in Table 1.

TABLE 1. The corrosion rate of the investigated coatings

Coating	Corrosion Rate, g/m ² ·h
Steel 45	2.84
12X18H10T+Cu	1.76
12X18H10T+Zn-Cu-Al	1.03
12X18H10T+Zn-Al	1.02
12X18H10T+Fe-Al	0.40
12X18H10T+Al	0.34
12X18H10T+Zr	0.19

Figure 1 illustrates electron microscope images of the investigated coatings.

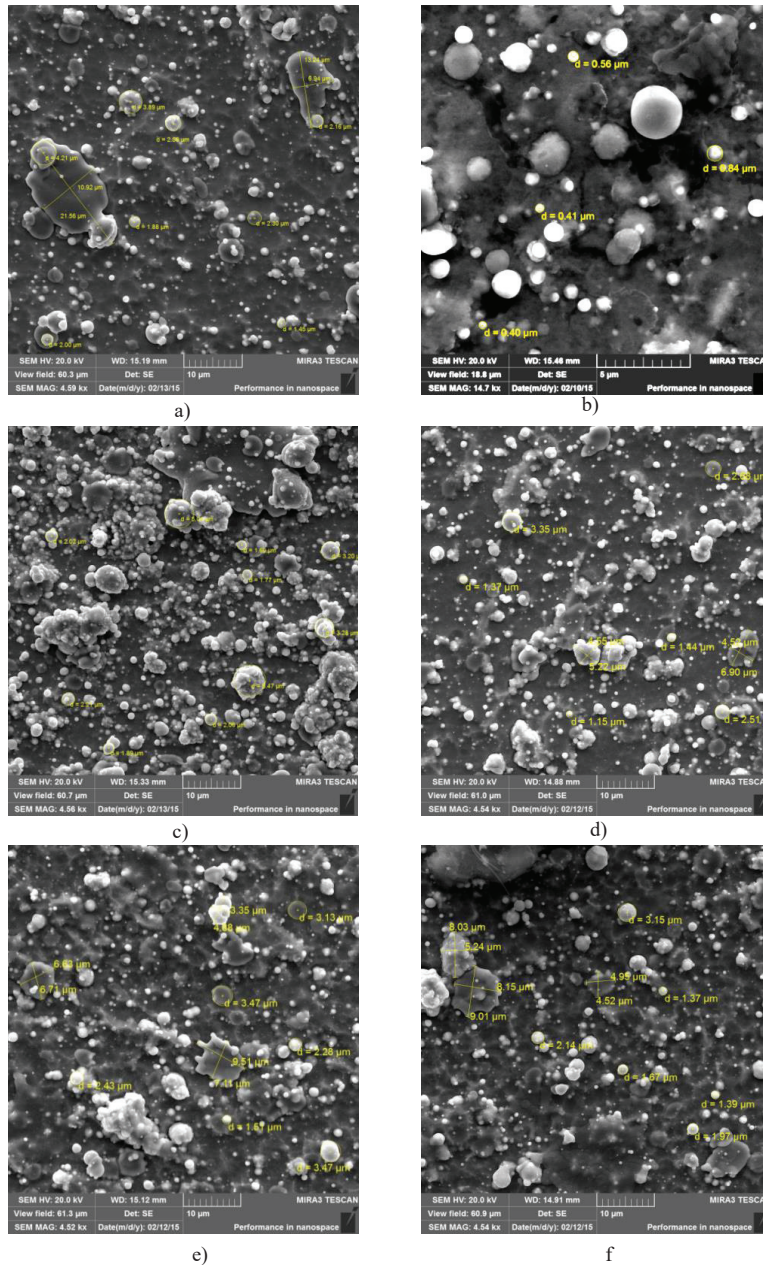


FIGURE 1. Scanning electron microscope images of multi-element coatings: a – 12X18H10T+Zr; b – 12X18H10T+Al; c – 12X18H10T+Cu; d – 12X18H10T+(Fe-Al); e – 12X18H10T+(Zn-Al); f – 12X18H10T+(Zn-Cu-Al)

Figure 2 illustrates AFM images of 12X18H10T+Cu coating showing the lowest corrosion resistance and 12X18H10T+Zr one showing the highest corrosion resistance.

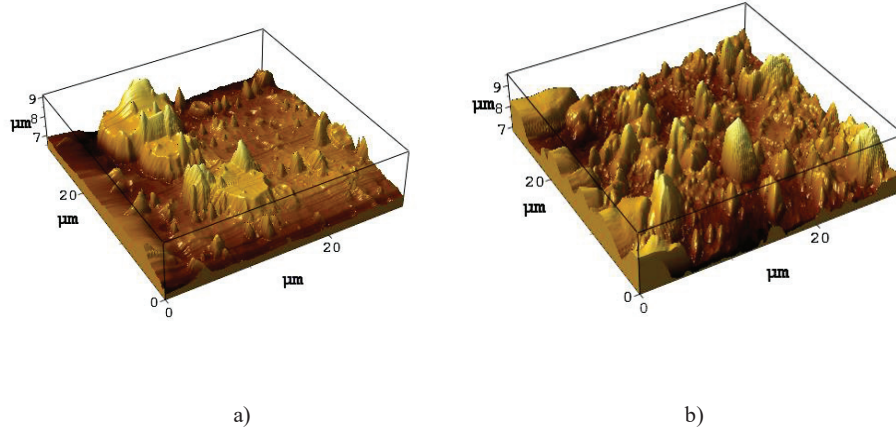


FIGURE 2. AFM images of the coatings 12X18H10T+Zr (a) and 12X18H10T+Cu (b)

The element composition of the coating is presented in table 2.

TABLE 2. The element composition of the coating 12X18H10T+Zr

Element	Weight, %	Element	Weight, %
N	10.36	Fe	25.82
Ti	0.23	Ni	3.69
Cr	8.77	Zr	42.84

DISCUSSION

The analysis of coatings images shows that there is an ordered columnar structure arising from the self-organization of plasma coatings. It is usually formed during solidification as a result of concentrated supercooling [7]. Since the melting area enriched in impurity is formed at the solidification front in forming the columnar structure, the appearance of impurity segregation at the cells boundaries is due to lateral diffusion of the impurity stream from the growing bead top. The amount of impurity that do reach the cell boundaries is difficult to measure, but it depends on the depth of recesses between the cells. In increasing supercooling the recesses between the cells become deeper, which leads to enrichment of the cell boundaries by impurity due to the diffusion of impurities from the cell. The impurity concentration on the boundaries can be several times greater than that in the cell center.

It is found that the corrosion rate decreases from 1.76 g/ m²h for 12X18H10T+Cu coating up to 0.19 g/m²h for 12X18H10T+Zr coating (Table 1).

The obtained results can be compared with the corrosion rate of some corrosion-resistant stainless steels (Table 3).

TABLE 3. The corrosion rate of the most corrosive-resistant steels

Steel Type	Corrosion Rate, g/m ² ·h
X23H28M3/Д3Т	0.21
X23H27M3Т	0.26
X18H12M3Т	0.80

The corrosion resistance of the greater part of the investigated coatings is seen to be quite high and not to be similar to the performance of the most corrosion-resistant steels. Thus, any of the coatings of the table 1 is significantly superior to the corrosion resistance of 45 steel, which is widely used as structural steel in the manufacture of oil and gas and oilfield equipment parts and components.

In [8] the thermodynamic model for the corrosion resistance χ the following expression is obtained:

$$\chi = \frac{kT}{C_1} \cdot \frac{A}{G^0},$$

where A the work of the "corrosive forces", T is temperature, G^0 is the Gibbs potential of the metal solid sample (pure metal is the Fermi energy E_F), k is the Boltzmann's constant, C_1 is a constant.

The work of the "corrosive forces" for surface and thin films is equal to the energy of their destruction, i.e., $A = \sigma \cdot S$, where σ is the surface tension, S is the specific surface area. Thus, the higher the corrosion resistance is, the greater the surface energy is (surface tension).

For the investigated coatings the surface tension values were determined by the work [9]. The calculated data are given in table. 4.

TABLE 4. Surface tension of the investigated coatings

Coating	$\sigma, \text{J/m}^2$	Coating	$\sigma, \text{J/m}^2$
12X18H10T+Cu	0.970	12X18H10T+Fe-Al	1.292
12X18H10T+Zn-Cu-Al	1.093	12X18H10T+Al	1.144
12X18H10T+Zn-Al	1.098	12X18H10T+Zr	1.445

The determined values of surface tension for the studied coatings are from 0, 970 j/m^2 for the less corrosion-resistant coating of 12X18H10T+Cu to 1,445 j/m^2 for the most corrosion resistant coating of 12X18H10T+Zr.

Since the surface tension σ is related to the melting point by the ratio [10]: $T_m = 1, 4 \cdot 10^3 \cdot \sigma$ (K), the refractory metals can be recommended as alloying additives for improving the coating corrosion resistance.

CONCLUSION

The corrosion resistance of the greater part of the investigated coatings is not similar to the most corrosion-resistant steels. To improve the corrosion resistance of metallic coating it is necessary to increase the surface tension by adding refractory metals in its composition. Such coatings can be recommended for protecting the parts and components of the oil and gas and oil-field equipment from corrosion.

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