Optimization of Deposited Coating Chemical Composition during Operation in Urea Medium

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Abstract. The article deals with the problem of optimization of the chemical composition of the deposited metal operating in the urea melt. To improve the technological properties and increase the resistance of the deposited metal against intergranular corrosion, manganese (0.5-1.8 pts. wt.) and niobium (0.3-1.8 pts. wt.) were introduced. The chromium content was varied in the range of 20-30 pts. wt., nickel – 3-8 pts. wt.

1 Introduction

Austenitic-ferritic deposited coatings have a combination of properties such as good weldability, high resistance against intergranular corrosion and corrosion cracking, which makes them promising structural materials for surfacing the sealing surfaces of check valves, pump parts and other equipment operating in any kind of aggressive medium [1].

The choice of materials for surfacing equipment parts still remains an unsolved problem. When manufacturing equipment operating in acidic corrosive medium, it is recommended to use austenitic surfacing materials. However, when working in an alkaline medium, the deposited coatings made of austenitic wires as filler material, undergo selective corrosion along the fusion line [2]. When using filler materials identical to the chemical composition base metal, selective corrosion occurs in the deposited weld metal.

2 Research Procedure

Surfacing was carried out on plates of steel 03Kh17N13M3T with the dimensions of 40x40x20 mm with experimental cast rods of the PNL-04Kh27N7M3D2B type [3] with a diameter of 5 mm and a length of 270 mm, in argon medium, with 180 A of current strength. Samples for testing 10x20x20 mm in size were cut from the upper layers of multilayer surfacing.

Heat treatment of the deposited samples was carried out in the *PM-12M2P-1200* muffle furnace in the modes set in operation [4].

Corrosion resistance tests were carried out on samples (thermally treated [4]) under the conditions of the production process (urea melt) (Table 1).

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Table 1. Test Results

Try No.	X ₁ (Cr)	X ₂ (Ni)	X ₃ (Nb)	X ₄ (Mn)	K, g/(m ² ·h)
1	28.35	3.80	0.58	1.12	0.2284; 0.1996; 0.1919; 0.2162; 0.2706
2	21.70	7.70	1.35	1.70	0.3383; 0.4187; 0.4428; 0.3982; 0.3734
3	23.20	5.65	1.24	1.50	0.2798; 0.2827; 0.2640; 0.2645; 0.3057
4	19.76	7.40	1.50	1.32	1.2785; 1.3723; 1.2818; 1.3393; 1.2984
5	22.60	6.14	0.95	1.60	0.6041; 0.6092; 0.6570; 0.6587; 0.3461
6	27.45	4.30	0.55	1.70	0.3794; 0.3580; 0.3455; 0.3218; 0.3461
7	20.80	7.06	1.57	1.25	0.9761; 0.9269; 0.9709; 0.9679; 0.9344
8	28.20	5.28	1.10	0.72	0.2210; 0.2041; 0.2110; 0.2210; 0.2110
9	21.45	3.02	0.42	1.00	0.6694; 0.6157; 0.6541; 0.6571; 0.6981
10	25.40	3.50	0.45	0.80	0.3032; 0.3027; 0.2881; 0.3057; 0.3020
11	23.90	6.60	1.33	0.60	0.2857; 0.3206; 0.3548; 0.3349; 0.2928

3 Research Results and Discussion

The corrosion rate of the deposited metal is taken as an optimization parameter.

The calculations were performed in two stages. At the first stage, the dependence of the corrosion rate of the deposited metal in the urea melt on the content of alloying elements was determined. At the second stage, the chemical composition of the deposited metal was optimized.

To process the experimental results, the approximation method by analyzing pair correlation was applied [5]:

$$K_i = f(x_i). \quad (1)$$

Dependence of the corrosion rate of the deposited metal on the chromium content (Fig. 1, a) is as follows:

$$K_1 = a_1 x_1^3 + b_1 x_1^2 + c_1 x_1 + d_1, \quad (2)$$

where a_1, b_1, c_1, d_1 – least square coefficients [6]. Dependences (Fig. 1, b-d) for nickel (K_2), manganese (K_4) and niobium (K_3) were determined in a similar way. According to the theory of multiple correlation, the set of equations represents a mathematical model of the dependence of the corrosion rate of the deposited metal on the chemical composition:

$$K = \sum_{i=1}^4 K_i(X_i), \quad (3)$$

where K_i – corrosion rate of the deposited metal depending on the content of the i^{th} element, g/(m²·h); i – number of optimization parameters.

Thus, the mathematical model has the following form:

$$K_0 = A_0 + A_1 X_1^3 + B_1 X_1^2 + C_1 X_1 + B_2 X_2^2 + C_2 X_2 + B_3 X_3^2 + C_3 X_3 + B_4 X_4^2 + C_4 X_4. \quad (4)$$

Owing to the solution of the equation system on a personal computer and determination of the coefficients, the following dependence of the corrosion rate of the deposited metal on the chemical composition was obtained:

$$K = 82.0295 + 0.7727 X_1^3 + 6.7041 X_1^2 + 9.3974 X_1 + 1.8638 X_2^2 + 12.3974 X_2 + 7.4978 X_3^2 + 3.4375 X_3 + 75.8217 X_4^2 + 171.0485 X_4. \quad (5)$$

Fig. 1. Dependence of the corrosion rate of the deposited metal on the content of chromium (a), nickel (b), niobium (c), manganese (d)

Further processing of the experimental results consisted in finding the optimal chemical composition of the deposited metal with high corrosion resistance in the urea medium by the steepest ascent method (the Box-Wilson method). According to the flowchart (Fig. 2), a computer program was compiled in FORTRAN 2018. The program included the calculation of the corrosion rate using the regression equation for the deposited metal, the chemical composition of which was selected by sequentially increasing the number of variable elements with a given step from the minimum to the maximum value. In addition, the corrosion rate was calculated for various values of the varied parameters.

The data block of the corrosion rate of the deposited metal, calculated depending on the number of elements, consisted of 1,260 variants. The best corrosion resistance was exhibited by the deposited metal containing 28.0 pts. wt. of Cr, 8.0 pts. wt. of Ni, 0.5 pts. wt. of Nb, 1.1 pts. wt. of Mn.

It is known that at ≥ 25.0 pts. wt. of chromium, the plastic properties of the deposited metal become deteriorated. Corrosion resistance in urea melt increases insignificantly when the amount of chromium changes in the range of 25.0-29.0 pts. wt. (Fig. 1, a). Therefore, its content was limited to the items from 26.0 to 28.0 pts. wt. To obtain the optimal phase composition, it is necessary to ensure the nickel content in the range of 7.0-8.0 pts. wt.

Fig. 2. Flowchart of the search program for the optimal chemical composition of the deposited metal

The results of corrosion tests of deposited samples (27.0 pts. wt. of Cr, 7.0 pts. wt. of Ni, 0.5 pts. wt. of Nb, 1.1 pts. wt. of Mn) showed that the corrosion rate made 0.01915 g/(m²·h) and was close to the corrosion rate of the deposited metal of the optimal composition calculated by the regression equation (0.01902 g/(m²·h)). The deposited samples of developed cast rods, after tests in the urea melt, showed no traces of local corrosion, which was general in its nature.

Based on the calculated and experimental data, the following optimal chemical composition of the deposited metal (pts. wt.) was determined: carbon 0.02-0.06; silicon 0.2-0.8; manganese 0.5-1.2; chromium 25.0-29.0; nickel 5.0-8.0; molybdenum 2.5-3.5; nitrogen 0.05-0.3; cobalt 0.15-0.4; niobium 0.45-0.75; cerium 0.01-0.1; copper 1.25-2.5; while iron made the rest.

To determine the process through, comparative tests of coatings deposited with experimental cast rods and UONI-13/N1-BK electrodes were carried out at a deformation rate of 0-30 mm/min in the shortness temperature range of 1,000-1,450°C. The strength of the metal deposited with experimental cast rods is high. The critical deformation rate of the deposited metal by the developed cast rods in the brittleness temperature range made 26 mm/min, while using UONI-13/N1-BK electrodes – 14 mm/min.

4 Conclusions

1. A mathematical model of the dependence of the corrosion rate of the deposited metal on the content of alloying elements (chromium, nickel, niobium, manganese) is proposed.

2. High corrosion resistance in urea medium, workability, strength and ductility are possessed by the deposited metal containing (pts. wt.) carbon 0.02-0.06; silicon 0.2-0.8; manganese 0.5-1.2; chromium 25.0-29.0; nickel 5.0-8.0; molybdenum 2.5-3.5; nitrogen 0.05-0.3; cobalt 0.15-0.4; niobium 0.45-0.75; cerium 0.01-0.1; copper 1.25-2.5; while iron makes the rest.

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