INVESTIGATION OF THE EXPLOITATION CHARACTERISTICS OF BELLOWS EXPANSION JOINTS MADE OF HEAT-RESISTANT NICKEL ALLOY

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Summary. Investigations of the macro- and microstructure, mechanical and technological properties of a metal strip made of heat-resistant nickel alloy Cr20Ni43Mo9Mn6Nb-vi were carried out. In order to determine the optimal composition of the pickling solution, studies were carried out on the use of various mixtures for pickling the surface of the strip. On the basis of the studies carried out, technological recommendations were developed for the preparation of materials before welding of bellows expansion joints.

Keywords: nickel alloy, heat resistance, bellows expansion joint, microstructure, oxide layer, corrosion testing, etching, austenization.

To ensure satisfactory exploitation characteristics of bellows expansion joints, it is necessary, in addition to observing the manufacturing technology, to control the state of the weld surface and the base metal, since it is this factor that determines the corrosion resistance, and, consequently, the durability and performance of the product.

Since the presence of temperature and force effects intensifies the chemical and electrochemical interactions underlying the ongoing corrosion processes [1], the chemical composition of the medium and the initial surface treatment of the material have a decisive effect on the rate and mechanism of corrosive wear under these conditions [2].

When high-alloy heat-resistant alloys are used for the manufacture of bellows, the thickness of the oxide film cannot be an indicator of corrosion, since it has high
resistance and low solubility in an aggressive environment. At the same time, the oxide layer formed on the metal surface can significantly affect the welding and technological properties of the material used [3], despite its insignificant thickness [2].

The aim of the work was to study the main performance characteristics of the samples of bellows expansion joints made of Cr20Ni43Mo9Mn6Nb-vi alloy.

The heat-resistant nickel alloy Cr20Ni43Mo9Mn6Nb-vi (EP941-vi) is used for the production of cold-rolled strip intended for the manufacture of welded parts of equipment for the oil and gas, chemical industry and power engineering, such as, for example, bellows expansion joints operating under temperature-force loading. Produced according to [4]. To achieve this goal, we analyzed the macro- and microstructure of samples of a metal strip made of steel Cr20Ni43Mo9Mn6Nb-vi, and also studied the effect of an oxide film on the technological and corrosion properties of welded samples.

Samples of cold-rolled strip made of alloy Cr20Ni43Mo9Mn6Nb-vi (EP941-vi) with dimensions of 250×100×0.28 mm were studied. According to [4], the strip is delivered after etching in a protective atmosphere, with etching, while a yellow-brown surface color is allowed. Macrostructural analysis of the samples also showed that the direction of rolling coincides with the traces of the rolls on the surface of the samples along the width of the strip.

The results of the chemical analysis of the samples showed that the chemical composition of the strip material meets the requirements [4]. According to [4], in the composition of the strip, deviations in the mass fraction of carbon + 0.01% are allowed. The yttrium content was not determined by chemical analysis. It should be said that, according to the literature, additional alloying with yttrium contributes to the modification and refining of the deposited metal, reduces the degree of contamination with non-metallic inclusions, increases the assimilation of alloying elements by welded seams, improves their strength and plastic characteristics, and also contributes to an increase in the impact toughness of the weld metal. It is also known that in corrosion tests in corrosive environments, specimens have greater resistance than metal without microadditives [5, 6]. The results of the chemical composition of the strip are shown in table 1 along with the standard values of the content of alloy constituent elements. The physical properties of the alloy are given in table 2.

Table 1

Comparative data of the chemical composition of cold rolled strip Cr20Ni43Mo9Mn6Nb

| Data type | Mass fraction of elements, % |
|-----------|-------------------------------|
|           | C    | Mn  | Si    | S    | P    | Cr   | Ni   | Mo   | Nb   | Y (calc.) |
| Sample    | 0.03 | 5.40| 0.11  | 0.03 | 0.003| 20.01| 44.22| 8.50 | 0.95 | –          |
| From [4]  | ≤ 0.02 | 4.5-6.5 | ≤ 0.2 | ≤ 0.015 | ≤ 0.025 | 19.0-21.0 | 42.0-44.5 | 8.0-10.0 | 0.9-1.3 | ≤ 0.15     |

[Author's development] & from [4]
The mechanical properties of the strip samples were determined at a temperature of 20 °C. For this, tensile tests were carried out on specimens with a design length of 50 mm.

| Physical properties of cold rolled strip Cr20Ni43Mo9Mn6Nb |
|-------------------------------------------------------------|
| Working temperature range, \( T, \) °C | Melting point, \( T_m, \) °C | Thermal expansion coefficient, \( \alpha, \) deg\(^{-1}\) | Thermal conductivity coefficient, \( \lambda, \) W/(m·deg) | Density of material, \( \rho, \) kg/m\(^3\) | Specific heat, \( C, \) J/(kg·deg) |
| 0÷500 | 1370÷1400 | (10.1÷17.1)×10\(^{-6}\) | 55.4÷75.5 | 8000 | 456 |

Data generated from [4]

The mechanical properties of the strip samples were determined at a temperature of 20 °C. For this, tensile tests were carried out on specimens with a design length of 50 mm.

| Mechanical properties of cold rolled strip Cr20Ni43Mo9Mn6Nb |
|-------------------------------------------------------------|
| Tensile strength, \( \sigma_b, \) N/mm\(^2\) | Yield strength, \( \sigma_{0.2}, \) N/mm\(^2\) | Relative extension, \( \delta_{50}, \) % |
| 640÷720 | 300÷380 | 41÷44 |

[Author's development]
studies were carried out using MIM-8, Axio Observer A1 microscopes and an MBS-2 binocular microscope. [7]

Before carrying out studies of the microstructure, electrolytic etching was carried out in a 10% solution of ammonium persulfate \((\text{NH}_2\text{SO}_4)\) at \(j = 0.5\ \text{A/cm}^2\). As a result, a single-phase austenitic structure was revealed, which is a nickel-chromium-molybdenum solid solution and a carbide phase \((\text{Me}_6\text{C})\) located in the matrix and along the grain boundaries (Fig. 3, a). We also carried out chemical etching of the samples in Villel's solution: \([\text{HCL} + \text{picric acid} + \text{ethyl alcohol}]\). As a result, as in the first case, a granular structure with a grain size of 4÷5 points according to GOST 5639 was revealed (Fig. 3, b) [7].

Fig. 1. The nature of the microstructure after electrolytic etching in a 10% solution of ammonium persulfate (a) and chemical etching in Villel's solution (b), \(\times200\)

To identify the structural components of the material of the samples and to determine the presence of nonmetallic inclusions, an increase of \(\times550\) was used. Fig. 2 shows samples of the microstructure of the Cr20Ni43Mo9Mn6Nb-vi alloy.

Fig. 2. Microstructure of the cold rolled strip Cr20Ni43Mo9Mn6Nb, \(\times550\)
According to the research results, it was found that in the austenitic structure of the metal of the samples, strips of finely dispersed carbide inclusions (Fig. 2, a), as well as larger inclusions of the intermetallic phase (Fig. 2, b) were revealed. This indicates the tendency of the material to nucleation and segregation of intermetallic and carbide phases under the influence of external factors [8]. Therefore, before further tests, the samples were austenitized at a temperature of 1070±1170 °C, followed by cooling in air.

Since the formation of local foci of corrosion occurs, in most cases, around non-metallic inclusions, for example, carbides, also in places of accumulation of dislocations and other defects, studies of the resistance of strip samples against intergranular corrosion were carried out.

The preparation of the surface of steel samples before testing consisted of grinding with emery paper with an abrasive grain size of 40 μm and electrochemical etching in a 10 % solution of oxalic acid with a current density of 0.9÷1.0 A/cm² for 1.5÷2 minutes. Corrosion tests were carried out in accordance with Appendix E of GOST 6032-2003 by method A on two samples according to the requirements of p. 3.4 [4] (Fig. 3, a).

The samples were kept in a solution of 16 % sulfuric acid with copper sulfate in a glass flask with a reflux condenser for 20±5 hours. The samples were preliminarily subjected to provocative heating at a temperature of 650 °C for 2 hours.

After testing the samples on a mechanical press were subjected to a z-bend (Fig. 3, b) and examined on the MBS-2 on both sides at a magnification of ×8, ×16. No cracks indicating intergranular corrosion were found, and no local foci of corrosion were found either. Thus, as a result of research, it was found that samples of cold rolled strip Cr20Ni43Mo9Mn6Nb-vi, used for the manufacture of bellows expansion joints, are not prone to corrosive wear as a result of local and intergranular corrosion.

Conclusions:

1. Studies of the effectiveness of various pickling solutions for removing the oxidized layer from the surface of the strip of Cr20Ni43Mo9Mn6Nb-vi (EP941-vi)
alloy showed that in order to reduce the effect of the formed oxide film on the performance properties of bellows expansion joints, it is necessary to use mixtures recommended for microstructural analysis of high-nickel heat-resistant alloys.

2. The main cause of corrosion damage to bellows expansion joints made of Cr20Ni43Mo9Mn6Nb-vi alloy is structural heterogeneity caused by the precipitation of secondary intermetallic and carbide phases from the austenite matrix. To increase the homogeneity of the structure, it is necessary to carry out additional heat treatment - austenitization.

3. On the basis of the research carried out, technological recommendations have been developed for the preparation of blanks for bellows expansion joints made of heat-resistant nickel metal alloy in order to increase the operational properties and reduce the tendency to corrosion destruction.

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