Enhancing the Lifetime of Welded Joints Using the Protective Coating and Causes the Formation of Defects in Them*

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Abstract. The paper shows the efficacy of eutectic Nickel coatings for protecting welded joints of steels against corrosion. It increases with increasing content of the eutectic and chemical compounds at the grain boundaries γ-solid solution based on Nickel. Refinement of the structure of the coatings and reduce their heterogeneity allows to increase the protective properties and durability of welded joints against corrosion.
It is established that the probability of formation of cracks in the coatings increases with their thickness, intensity of heating and cooling after reflow, and also with increasing content of the eutectic and chemical compounds at the grain boundaries γ-solid solution based on Nickel. Shown to prevent the formation of cracks in the coatings when they are melt you can use optimal modes of heating and cooling of the composition. Modification of the structure of the coatings by grinding them and reducing heterogeneity allows to improve the resistance to crack formation and protective properties of welded joints against corrosion.

Introduction

The service life of welded joints is determined both by the strength of their material and surface properties [1-4]. Practice technical operation of the equipment shows that the majority of their products working in the conditions of corrosive environments and loads varying in magnitude and sign. Therefore, the reliability and durability of such products is determined by the corrosion resistance of their working surfaces, strength and endurance of welded joints.

The problem of increasing the strength and reliability of welded joints of pipes of low-alloy steels is connected with the need to ensure the complex physico-mechanical properties and equal the strength of the connection zones, the prevention of cold cracking, as well as structures that reduce the resistance of connection delayed fracturing.

The increased service life of products with welded joints by protecting their surfaces against corrosion is an actual scientific-technical task. One of the effective ways to increase the service life of these products is the use of protective coatings. To predict the reliability and durability of welded joints with protective coatings under operating conditions allows the evaluation of their performance in terms of corrosion.

The use of coatings of alloys based on Nickel to protect welded joints against corrosion is limited by their susceptibility to cracking and the formation of pores.

The purpose of the work. The study of the causes of defects such as cracks and pores, reducing protective properties. Evaluation of possibilities of use of the coatings of eutectic Nickel alloys to protect the surfaces of welded joints against corrosion, increase the service life of products.

Research methods.

Welding of pipes from steels 10Г2С was performed using the power source inverter type MP 2400 company "KEMPPI". For coating used powder materials of Ni-Cr-B-Si-alloys. The substrates were low carbon steel. The coating was applied by welding or argon-nitrogen plasma, subsequent melting. Used various methods of reflow coatings: flame, plasma, laser, electron beam. In research of influence of processes of surfacing and melting coatings on the structure and properties of the compositions used data on surface heating steel in a gas flame, plasma jet, laser and e-beams [5-8]. Certification of the structure of the coatings and the zone of welded joints was carried out on an optical microscope MIM - 9. Conducted qualitative assessment of the impact of melting on the structure of the coatings.

The results of the study

In the production of high activity of technological media exacerbates the total value of wear parts and equipment. The intensity of wear depends on flow rate, chemical conditions, duration of work, presence of abrasive inclusions, and other factors. In terms of the dynamic effects of corrosion and corrosion - abrasive media service life of product is drastically reduced.

A lot of products, working in conditions of corrosive environments, pitting at the same time exposed or threat intercrystalline corrosion and intensive abrasive wear, which is produced in the working surface, accompanied by failure.

In this paper, we propose a combined technology of surface protection of large-size products by combining the operations of welding, electric arc and electron beam welding and melting coatings of Nickel alloys [5-9]. This method allows to solve simultaneously two tasks - to improve the performance of the products and prolong their service life [5, 9]. Such problems can be solved by combination of two operations to replace worn-out fragments of the goods by cutting them and welding of inserts, for example, bypasses the tubes with the operations applied to the weld joint area of protective coatings and their subsequent melting (figures 1, 2). This approach is implemented in the protection of surfaces chemical containers.

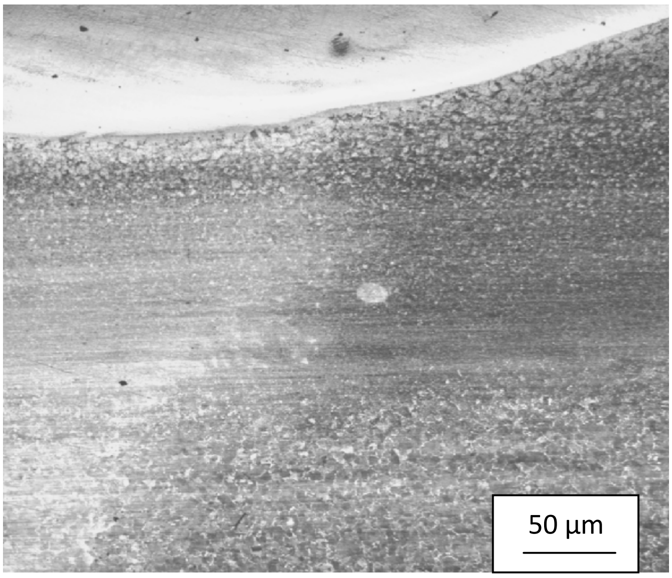

Figure 1 - Structure of the transition zone "of the deposited coating PG-12N-02 – a welded joint of steel 10Г2С"

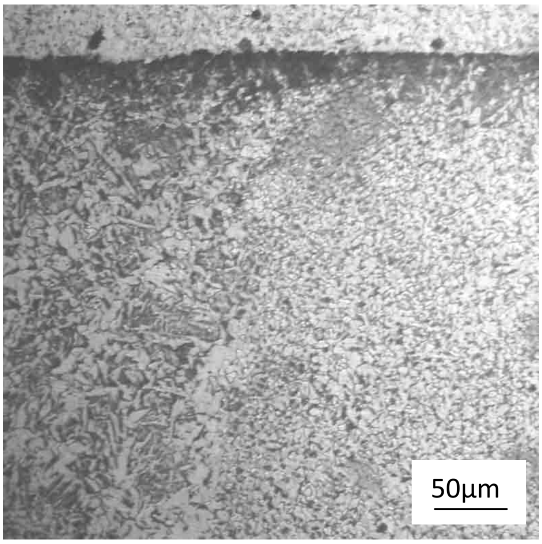

Figure 2 - Structure of the composition "melted coating PG-12N-02 – a welded joint of steel 10Г2С".

In metals, when the erosion occurs through the formation of craters and ductile fracture their edges, the grain size does not play a role if they are larger than the diameter of the crater. However, if these sizes become smaller than the diameter of craters, the erosion resistance increases dramatically. On the basis of qualitative indicator of the corrosion resistance (the change in appearance of the surface) evaluated coatings: "with firmness" - "unstable"; "fit" - "unsuitable" (table).

Table - Chemical resistance of steels and coatings

Of korrozion-tion environment	A temperature of medium, °C	Materials				
		Carbon steel	PG-10N-01	PG-10N-03	PT-19N-01	PS-12H-VK
H_2SO_4	60	D	B	D	B	D
HNO_3	50	D	C	D	C	C
HCl	30-70	D	D	D	D	D
H_2CO_3	120	C	B	B	B	B
NaOH	30-40	B	D	D	B	D
NaCl	30-50	C	B	D	B	B
H_2O	20-140	C	A	B	B	A
Na_2SO_4	0-50	C	B	B	C	B
NH_3	40-120	C	A	D	B	C
CH_2O	30-70	B	B	B	B	B

Note: A, B, C and D groups of resistance of materials against corrosion,
correspond to corrosion rates (mm/year): 0,00 - 0,05; 0,05 - 0,1; 0,1 - 0,5; > 0,5

The change in appearance was also assessed by conventional scales scores (according to GOST 9.076-77). At the final stage of the process of corrosion wear of the coating lead to their cracking and subsequent failure.

The performance of the coatings is determined by their structural features. A large heterogeneity of the coatings on the dispersion and distribution of the phases determines the unevenness of processes of wear leads to the formation in the areas of defects of cracks with the subsequent chipping of fragments, which decrease the performance of the stock bearing capacity.

In the formation of coatings with crushed structure and more uniform distribution by volume of carbide and boride phases decreases the size of the collapsing fragments and increase performance properties. The smaller the coating structure, more local nature of the centres of destruction. High resistance of fused coatings is determined by their high strength and structure of supersaturated γ-solid solution Nickel-based distributed fine-grained inclusions of carbide and boride phases, the eutectic of γ-Ni+Ni_3B and alloy γ-Ni+$Cr_{23}C_6$.

In the process of cooling of welded joints with protective coatings [5] at temperatures close to the solidus temperature of the alloy, the coatings are formed by "hot" (crystallization) cracks [6, 9-10]. Their appearance caused by the process of heating and crystallization during cooling of the composition, when heat and are unevenly distributed temperature in the cross section, and, as a result of heating, the coating is compressed, and upon cooling will occur tensile stresses. This occurs under the influence of the processes of lengthening and subsequent shortening of the base metal composition.

When the degree of deformation exceeds the deformation of the composition of the crystallizing ability of the coating, it becomes possible appearance of hot cracks (figure 3).

The probability of their formation increases with increasing content of the eutectic and chemical compounds, crystallizing the grain boundaries of the Nickel γ-solid solution at low temperatures and decreasing the ductility of coatings [10-14]. With the increase of coating thickness, the intensity of their heating and cooling after reflow, the possibility of cracking also increases.

Because the deformation ability of coatings of Nickel alloys is relatively low, occurring during cooling of the compositions after reflow relaxation of residual stresses can lead to the formation of a "cold" brittle cracks.

These cracks occur most often at temperatures around 200 °C due to the occurrence of structural transformations in the coatings and are connected, for example, with the formation in the steel base of martensite as the result of quenching [11, 13, 14].

To prevent the process of formation of cold cracks occurring in the investigated coatings, it is necessary for each of the compositions is to carefully select the modes of heating and cooling when fusing the coatings.

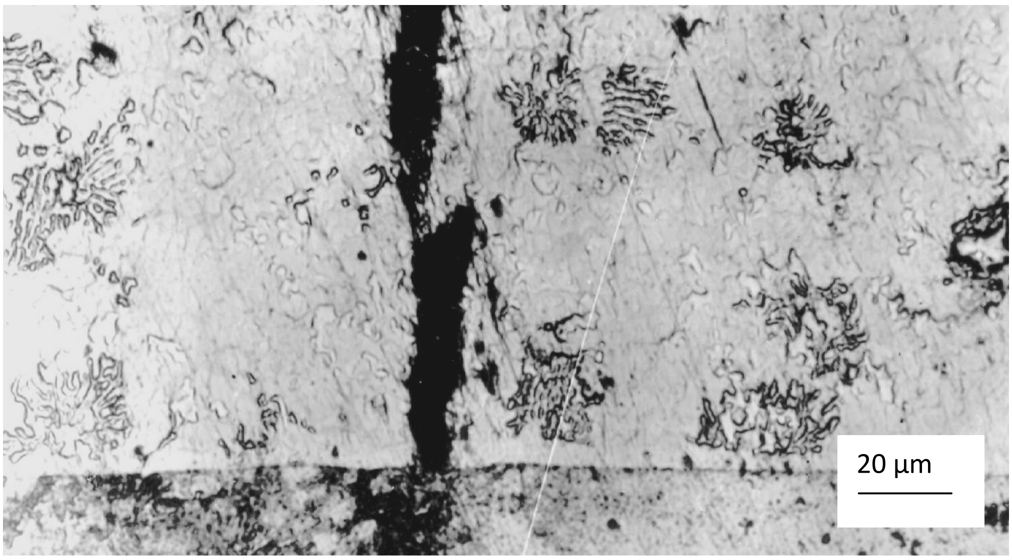

Figure 3. The formation of solidification cracks in the fused coating of PG-10N-01 "outlets" alloy γ-Ni-Cr_{23}C6.

Therefore, the use of high-speed and high-energy methods of heating such as laser and electron beams that have many advantages, but producing local intense heating fundamentals, may lead to cracking of the coatings.

This is because the speed of heating and cooling due to uneven local thermal effect and heat sink there are such a high voltage, which lead to the formation of cracks. Thus, in laser and electron beam melting methods because of the very high speed of crystallization of the molten coating often formed "hot" (crystallization) cracks caused by high levels occurring residual stresses and their non-uniform distribution by volume. This is because in such methods, the reflow occurs, in fact, almost complete or, sometimes, the complete dissolution of hardening carbide and boride phases in Nickel γsolid solution. During the subsequent rapid cooling crystallizing coating dissolved in it the elements do not have time to stand and there is a strong local supersaturation plots γ-solid solution. On the borders between these areas and the Nickel matrix, there is tension, leading to the formation of "hot" (crystallization) cracks. The centers of origin can also be and borides and carbides of lamellar eutectic γ-Ni+Ni_3B and alloy γ-Ni +$Cr_{23}C_6$.

The application of volumetric methods of heating (furnaces) and deep warming up the foundations in the flame melting with subsequent relatively slow cooling avoids the formation of cracks in the coatings.

Cause cracking of coatings formed on a steel substrate, the cooling which is sometimes accompanied by martensitic transformation, is that the coating in the cooling period shrinkage, and base metal expansion. To prevent the process of cracking of the coatings is possible by carrying out slow cooling with the furnace, sand, asbestos, etc. or isothermal aging at a temperature of intensive transformation of austenite. Enhancing the resilience of the material of the coatings to the formation of cold cracks contributes to the change of their structure in various ways, accompanied by a decrease in the degree of chemical and structural inhomogeneity of these coatings. In laser and electron beam melting, ultrasonic treatment is a strong refinement of the structure of coatings that reduce the probability of formation of cold cracks. However, at the same time, increase speed of heating and cooling in laser and electron-beam exposure causes the increase in the level of internal stresses, and, as a consequence, the probability of formation of cold cracks in the coatings.

The tendency of the coatings to the formation of hot cracks increases with the growth of the volume content of carbides $Cr_{23}C_6$ and Cr_7C_3, [11, 13, 14].

Stereometric analysis of the coatings performed in the work showed that their porosity, including pore size, number, shape and volume distribution strongly depend on the modes of reflow. Coating, melted in a furnace at temperatures ≤ 1050 °C and short times of exposure (≅ 1 min), have a significant porosity (10 - 12 %, vol.). The pores are predominantly spherical in shape, have dimensions of 20 μm and is uniformly distributed over the volume of the coating. At higher temperatures (1050 - 1150 °C) and exposure times ≅ 1 - 5 min cake mix low-porous coatings are formed (≅ 4 - 6 %, vol.). Pores (with sizes up to 10 μm) are observed mainly near the surface of the base (figure 4). The exception is if the reflow of the sputtered coatings with friable (loose) structure.

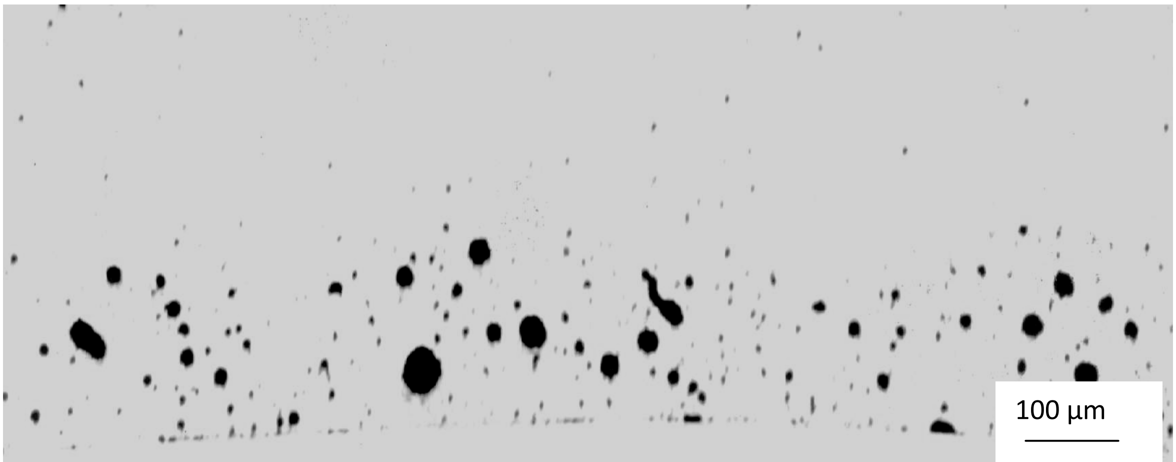

Figure 4. The concentration of pores in the boundary layer of coating at high-speed methods of reflow.

Summary

1. The probability of formation of cracks in the coatings used to protect the welds from corrosion increases with increase in the thickness of these coatings, the intensity of their heating and cooling after reflow, and also with increasing content of the eutectic and chemical compounds, crystallizing the grain boundaries of the Nickel γ-solid solution.

2. To prevent the formation of cracks in the fusing the coatings is possible only with selection of modes of heating and cooling of the composition of each species or isothermal aging at a temperature of intensive transformation of austenite.

3. To increase the resistance of the coatings to cracking, and protection of welded joints against corrosion is possible by modifying the structure of these coatings: grinding and the reduction of heterogeneity.

4. The use of eutectic Ni-Cr-B-Si-alloys can be effective in creating protective coatings for welded joints of steels.

5. The increase in the content of alloying elements in Ni-Cr-B-Si alloys leads to an increase of the volume content of the eutectic of γ-Ni+Ni_3B, alloy γ-Ni+$Cr_{23}C_6$, carbides and boride phases, the increase of strength and corrosion resistance melted and deposited protective coatings and welded joints of steels in General

References

[1] Welded construction. Mechanics of destruction and criteria of serviceability) / V. A. Vinokurov, S. A. Kurkin, G. A. Nikolaev; - ed B. Paton. - M.: Mashinostroenie, 1996, 576 p
[2] Fracture toughness and mechanical properties of structural materials technical systems / V. V. Moskvichev, N. And. Makhutov N., A. P. Chernyaev and others. - Novosibirsk: Nauka, 2002, 334 p.
[3] Lebedev B. F., Pashin G. A., Dudko M. S. the Dependence of impact strength HAZ of welded joints of low alloy steels of the specific energy at welding // Automatic welding. - 1987. - No. 4. - P. 7 - 9.
[4] Saraev Yu. N., Sleptsov O. I., Bezborodov V. P., Nikonova I. V., A. V. Tutev. Analysis of fatigue fracture, the structure and properties of welded joints of pipelines operating in conditions of Siberia and the far North/Installation and special works in construction. - 2005. - No. 8. - P. 18.
[5] Saraev Yu. N., Bezborodov V. P., Selivanov Y. V., Nikonova I. V. The Influence of modes of surfacing coatings on corrosion resistance in acidic environments of welded joints of austenitic steels//metal finishing. - 2007. - № 2. - P. 33 - 36.
[6] Gryazev A. N., Poltev G. L., Kondrat'ev, I. P. Features of the formation of cracks during laser cladding of nickelchromium alloys// Welding production, 1989, №. 9, P. 10 - 12.
[7] Dubasov, A. M., On thermal processes during solidification of the coating particles in plasma spraying//Welding production, 2000, № 2, P. 25 - 28.
[8] Berdnikov A. A., Filippov M. A., Studenok, S. E. Structure of hardened carbon steels after plasma surface heating// materials Science and heat treatment of metals, 1997, № 6, P. 2 - 4.
[9] Larionov V. P., Sleptsov O. E., Saraev Yu. N., Bezborodov V. P. New approaches to the development of modern technologies of welding and coating to ensure the operational reliability of metal structures and products, operating in conditions of Siberia and the far North/Bulletin of the Academy of military Sciences. - 2008. - № 3. - P. 67.
[10] Zbriger A. G. Structure and properties of coatings of tamifluswine alloys//Metallography and heat treatment of metals, 1988, № 4, P. 42 - 44.
[11] Doroshenko L. K., Borisova A. L., Grigorenko G. M. and others. The Processes of melting and crystallization of coatings from tamifluswine Nickel alloys//Automatic welding, 1990, Vol. 10, P. 22 - 23.
[12] Oshchepkov, Y. P., Oshchepkova N. In. Metallographical study tamifluswine carbide powders//Automatic welding, 1976, № 11, P. 32 - 35.
[13] Klinskaya - Rudenskaya N. A., Kopysov V. A. Features of composite coatings based on Ni-Cr-

Si-alloy. The study of the microstructure of coatings//Physics and chemistry of materials processing, 1995, № 1, P. 69 - 81.
[14] Antonova E. A., Andrushchenko N.S., Sinai L. M. Interaction of the coating Ni-Cr-Si-B with steel in the process of fused deposition modeling // Protection of metals. 1971. - T. 7. - Vol. 2. - P. 137 - 142.

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