Use of coatings for protection of welded joints of steels, their structure and properties

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Abstract. The paper studies the structure and demonstrates the efficiency of application of eutectic nickel coatings for protection of welded joints of the 10G2S-type steel from corrosive action. It increases simultaneously with the increase of eutectic content and chemical compounds along the grain boundaries of the $\gamma$-solid solution based on nickel. The refinement of the coatings’ structure and the reduction of their heterogeneity allow enhancing the protective properties and resistance of welded joints to corrosion.

1. Introduction
The operational life of welded joints made from 10G2S-type steels is defined by both their material strength and surface properties [1–4]. The practice of technical maintenance of the equipment shows that the majority of products function under conditions of corrosive environment and varying loadings. Therefore, the reliability and durability of the operation of such products are determined by corrosion resistance of their working surfaces, by strength and endurance of welded joints.

The increase of the operation life of the products made from the 10G2S steel with welded joints by means of protecting their surfaces from corrosion is an urgent scientific-technical problem. One of the efficient methods of the operating life increase is the use of protective coatings. The use of the coatings made from nickel-based alloys for protection of welded joints from corrosion is limited by their susceptibility to cracking and pore formation.

The objective of the paper is the research of reasons of defect precipitation in the form of cracks and pores reducing the protective properties of coatings, as well as the assessment of possibilities of using coatings made from eutectic nickel alloys for the purpose of protection of welded joints’ surfaces from corrosion.

Welding of pipe fragments made from 10G2S steels was performed using inverter-type power supply MP 2400 by “KEMPPI” Company. Powder materials made from Ni-Cr-B-Si-alloys were used to apply the coatings. Low-carbon steels were used as base materials. The coatings were applied by means of facing or argon-nitric plasma with subsequent flowing. A qualitative assessment of the influence of the flowing on the coatings’ structure was made.

In the production, high activity of process media exacerbates the combined value of wear of parts and equipment. The wear intensity of parts depends on the velocity of the flow, the chemical activity of the medium, duration of the running period, the presence of abrasive inclusions, and other factors. Under conditions of dynamic impact of corrosive and corrosive-abrasive media, the operation life of products reduces drastically.

Many products, operating under conditions of corrosive media, are simultaneously subjected to pitting or dangerous intercrystalline corrosion and intensive abrasive wear, as a result of which the
wear-and-tear of the working surface, accompanied by failure, occurs.

The paper suggests application of the technology of combined protection of surfaces of large-sized products by combining the operations of welding, facing, and flowing of coatings made from nickel alloys [5–7]. Such method allows extending the operation life of the products. The problem can be solved by applying protective coatings on the area of the welded joint with their subsequent flowing (figure 1).

![Figure 1. The structure of the composition “flowing coating PG-12N-02 – the welded joint of the 10G2S steel”.](image)

In steels, when erosion occurs by means of craters’ formation and ductile fracture of their edges, grains’ sizes do not have much influence if they are greater than the crater diameter. However, if these sizes become less than the craters’ diameter, erosion resistance increases drastically. Based on the qualitative index of corrosion resistance (changing of the surface appearance), the coatings were assessed as: “stable” – “unstable”; “acceptable” – “unacceptable” (table 1). The corrosion stability was assessed in numbers of conventional scales (according to GOST 9.076-77). The working capacity of the coating is defined by its structural peculiarities. After flowing, the grains’ sizes are 30–40 µm. The grains’ sizes of the γ-solid solution strongly depend on the composition of the alloy and the flowing temperature, as well as on the coating thickness: the thicker it is, the coarser the coating structure is, which is related to the increase of the coating crystallisation period.

| Corrosion medium | Medium temperature, °C | Carbon steels | PG-10N-01 | PG-10N-03 | PT-19N-01 | PS-12N-VK |
|------------------|------------------------|---------------|-----------|-----------|-----------|-----------|
| H₂SO₄            | 60                     | D             | B         | D         | B         | D         |
| HNO₃             | 50                     | D             | C         | D         | C         | C         |
| HCl              | 30–70                  | D             | D         | D         | D         | D         |
| H₂CO₃            | 120                    | C             | B         | B         | B         | B         |
| NaOH             | 30–40                  | B             | D         | D         | B         | D         |
| NaCl             | 30–50                  | C             | B         | D         | B         | B         |
| H₂O              | 20–140                 | C             | A         | B         | B         | A         |
| NH₃              | 40–120                 | C             | A         | D         | B         | C         |

Note: A, B, C, and D are the groups of materials’ resistance to corrosion, which correspond to corrosion rates (mm/year): 0.00–0.05; 0.05–0.1; 0.1–0.5; > 0.5.
Heat removal in the coating area, adjoining the basis, occurring at a high rate causes the growth of column dendrites oriented normally relatively the basis by the axes of the first order. As the content of alloying elements in the alloys increases, the formation of a more finely-dendrite structure occurs. As a rule, the coating after flowing represents a material with features of both hypoeutectic and hypereutectic alloys. Formation of either structure depends predominantly on the initial composition of the powder material and conditions of coating obtainment. More often, in the coating, all types of structures are simultaneously fixed on different areas. When increasing the content of alloying elements in the coating by application of the more alloyed powder material, the content of carbide and boride phases increases and that of the $\gamma$-solid solution decreases. Dilute alloys are mainly characterised by the hypoeutectic structure; high alloys – by the hypereutectic structure with the high content of carbides and borides. Formation of coatings with the hypoeutectic structure leads not only to an increase of the plasticity of the material, but also to a certain reduction of hardness and strength. This allows using the material with such coating as a basis when creating compositions withstanding substantial mechanical loads. The structure of hypoeutectic nickel alloys consists mainly of the matrix represented by grains of the $\gamma$-solid solution and $\gamma$-Ni + Ni$_3$B eutectic with the volume content of up to 20% filling the spaces between nickel grains (figure 2).

The coatings cooled at different rates contain different amount of eutectic. An increase of the cooling rate owing to an increase of the thickness or volume of the basis metal results in a reduction of sizes of eutectic colonies.

![Figure 2](image_url)  
**Figure 2.** The structure of flowed coating PG-10N-04 with $\gamma$-Ni+Ni$_3$B eutectic along $\gamma$-Ni grains’ boundaries after cooling.

Large heterogeneity of the coating by dispersity and phase distribution predetermines nonuniformity of the corrosion processes’ behaviour and leads to formation of cracks in the defect areas with subsequent pitting of fragments. When forming the coating with the refined structure and more uniform distribution of carbide phases throughout the volume, the reduction of fragments’ sizes and enhancement of service properties occur. High resistance of the coating is determined by its structure and high strength.

With the increase of the coating thickness, the intensity of its heating and cooling during crystallisation, the probability of crack formation increases. Prevention of the crack formation process is ensured by selection of heating and cooling modes of the coating. The application of volumetric methods of the heating and deep heating-through of the basis with subsequent relatively slow cooling allows avoiding cracks formation. This is also facilitated by isothermal soaking at a temperature of intensive austenite transformation and refinement of the coating structure accompanied by the reduction of the degree of chemical and structural heterogeneity. Stereometric analysis of the coating showed that its porosity including the pore sizes, quantity, shape and distribution throughout the
volume strongly depend on the flowing modes. The coating flowed at temperatures of \( \leq 1050 \, ^{\circ}\text{C} \) and short soaking times (1 min) has significant porosity (10–12 \%, vol.). The pores are of spherical shape, up to 20 \( \mu \text{m} \) in sizes, and are uniformly distributed throughout the coating volume. At higher temperatures (1050–1150 \( ^{\circ}\text{C} \)) and soaking times of 1–5 min, low-porosity coatings (4–6 \%, vol.) form.

2. Conclusions
1. The probability of crack formation in the coatings used for protection of welded joints from corrosion increases with the thickness growth of these coatings, heating and cooling intensity during crystallisation, as well as during increasing the content of chemical compounds.
2. Crack formation in the coating can be prevented only by selecting the heating and cooling modes of the composition, or by soaking at a temperature of intensive austenite transformation.
3. Modification of the structure of these coatings by refining and reducing heterogeneity allows increasing resistance of the coatings to crack formation and enhancing protective properties of welded joints from corrosion.
4. The increase of the content of alloying elements leads to the growth of the volume content of carbide phases, to the increase of the strength and corrosion resistance of protective coatings, made from Ni-Cr-B-Si-alloys, and welded joints of steels on the whole.

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