Welding of ring joints of field pipelines with internal corrosion-resistant surfaced layer

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Abstract. The purpose of this work was to study the issues of ensuring the standard quality indicators of installation of welded pipes of field pipelines with a deposited layer of high-chromium steel. The research was performed on pipes made of steel 09G2S of the K48 strength category with a diameter of 258 mm and a wall thickness of 6 mm. The formation of the deposited layer on the inner surface of the pipe ends was performed by electric arc welding in protective gases with a wire SV-12X13 with a diameter of 1.2 mm. Welding of ring joints of pipes was performed with LB-52U type E50A electrodes according to GOST 9467 in accordance with the developed technology. Experimental testing of welding technology with an assessment of the quality of the resulting welds and their corrosion resistance was evaluated using non-destructive and destructive testing methods. Research results have shown the possibility of obtaining a corrosion-resistant welded joint with appropriate quality standards. Regulatory requirements for the welded connection of pipes with an internal surfaced layer were defined, which can be used in the implementation of projects for the construction of field pipelines with this design. It was shown, that to provide normative values of mechanical properties of welded joints of pipes with internal weld layer requires the development of additions to existing welding technology to the preparation of pipes prior to welding and temperature control prior and concomitant heating, to avoid embrittlement of the metal of the root seam layer when its alloying.

1. Introduction

One of the most common causes of failure of field pipelines is carbon dioxide corrosion [1]. The use of pipes made of carbon and low-alloy steels with an internal polymer coating instead of pipes made of corrosion-resistant high-alloy steels significantly reduces the cost of construction. However, it has a number of difficulties associated with providing anti-corrosion protection of the inner surface of ring welded joints. This problem is currently solved in various ways [3,4], and one of the most promising ways to ensure long-term anti-corrosion protection of joints is the use of pipes with a layer of corrosion-resistant steel deposited on the inner surface of the end sections.

The high-alloy metal coating at the ends of the pipes should protect the inner surface on the section between the anti-corrosion polymer coating and the mounting weld, as well as provide alloying of the root of the weld to achieve the necessary corrosion resistance.

In addition to surfacing, there are a number of other technologies for protecting welded pipe joints that create a corrosion-resistant layer in the weld zone, such as the use of lining rings, tips, cladding and spraying. However, surfacing is a more technological and easily implemented method of preparing pipes in the factory, and is also better suited for nondestructive testing after welding non-
rotating joints on the line. At the same time, this method of protecting welded pipe joints from corrosion is not without difficulties inherent in welding of double-layer steels [5, 6, 7].

The purpose of this work was to study the issues of ensuring the standard quality indicators of installation of welded pipes of field pipelines with a deposited layer of high-chromium steel.

2. Method
The research method can be divided into the following tasks, which were solved sequentially:

- formation of requirements for the required level of mechanical properties of welded pipes with a high-chromium deposited layer based on the current regulatory documentation;
- prediction of the structure and properties of the weld metal based on the chemical composition of the pipe metal, surfacing and welding materials, geometric parameters of the weld and welding modes;
- development of requirements for preparation of pipes before welding and for welding modes;
- experimental testing of welding technology with an assessment of the quality of the resulting welds and their corrosion resistance.

The research was performed on pipes made of steel 09G2S of the K48 strength category with a diameter of 258 mm and a wall thickness of 6 mm. The formation of the deposited layer on the inner surface of the pipe ends was performed by electric arc welding in protective gases with a wire SV-12X13 with a diameter of 1.2 mm. After surfacing, the welding edges were machined to create a cutting edge-type C17 according to GOST 5264-80. Welding of ring joints of pipes was performed with LB-52U type E50A electrodes according to GOST 9467 in accordance with the developed technology.

The quality of the obtained welds was evaluated using non-destructive testing methods (visual measurement control, radiation control methods, ultrasonic control) and destructive testing methods with microstructure research, hardness measurement, uniaxial tension, impact and static bending tests. The corrosion resistance of the weld metal and the deposited layer was assessed by gravimetric method on samples cut from the control welds.

3. Requirements for mechanical properties of welded joints of pipes with a high-chromium deposited layer
The problem of substantiating the requirements for welded joints made of double-layer steels is aggravated by the lack of technical solutions with this design in the current regulatory documentation. To determine the requirements for the required level of mechanical properties of such welded joints, the analysis of normative documentation for welding ring joints of pipes for various purposes was performed. A summary of the requirements of various regulatory documents for indicators of mechanical properties of welded joints is presented in table 1.
Table 1. Requirements for the mechanical properties of mounting welded joints of pipelines.

| Indicator | GOST R 55990-2014 “Field pipelines. Design standards” | GOST 32569-2013 “Technological steel pipelines. Requirements for the device and operation in explosive and chemical hazardous industries” | SP 75.13330.2011 (SNiP 3.05.05-84) “Process equipment and process pipelines” |
|-----------|---------------------------------------------------|---------------------------------------------------|---------------------------------------------------|
| Ultimate strength | not lower than the standards set for the base metal | For Si-Mn steels-not less than 80°; For Cr-steels-not less than 50°; For austenitic-ferritic steels-not less than 80°; For austenitic steels - not less than 100°. | Low-alloy steels-80°; Heat-resistant steel -50°; Martensitic-ferritic class-50°, Austenitic class-100°. |
| Bending angle | For pipes up to K60 incl. - arithmetic mean is not less than 120°, minimum value is not less than 100° | For Cr-steels-no more than 240 HV (weld); For austenitic-ferritic steels - no more than 220 HV (weld); For austenitic – no more than 200 HV (weld). |
| Hardness | Up to K55 incl.: Welding seam-no more than 280 HV10; HAZ-no more than 300 HV10. | For a temperature of +20 °C: Si-Mn-steel and Cr-steel KCV-not less than 35, KCU-not less than 50; austenitic-ferritic KCV-at least 30, KCU – not less than 40. For temperatures below -20 °C: Si-Mn-steel and austenitic-ferritic KCV-not less than 20, KCU-not less than 30. |

4. Predicting the structure of the weld metal

A feature of welding pipes with double-layer steel in the weld zone is the formation of a variable chemical composition in the root layer of the seam, depending on the composition of the base metal of the pipes and the deposited layer, the brand of the electrodes used, the geometric parameters of the weld and welding modes. To evaluate possible structures formed in the root layer of the seam, the chemical composition of the seam was calculated at different proportions of high-chromium deposited metal. The expected structural and phase composition was analyzed using the Schaeffler diagram.

The share of the deposited high-alloy alloy in the root layer of the weld can be roughly estimated based on the thickness of the deposited layer and the width of the reverse roller of the root layer of the seam on the inner surface of the pipe. So for the thickness of the deposited layer of 1.0-1.5 mm, with a roller width of 8-12 mm, the expected share of the surfing metal in the root layer of the seam will be in the range of 15% to 50%, which will provide conditions for the formation of a martensitic-ferritic or martensitic structure.

The formation of a martensitic structure leads to the danger of cold cracks when the metal of the root passage is cooled below 400 °C. This fact requires taking additional measures both to limit the share of the metal internally surfaced, and to regulate the heat input in the welding process.

5. Requirements for welded pipes and welding modes

An important element of the development of technology for welding pipes with internal surfacing is the regulation of requirements for the geometry of the edges of the welded pipes. The share of the deposited metal in the root pass depends on the thickness of the coating, the shape of the cutting and the size of the welding gap. Regulation of these parameters is a necessary condition for ensuring the constancy of the characteristics of the resulting welded joint.

Regulating the running energy of welding, as well as the temperature of preheating and accompanying heating, are effective ways to reduce the cooling rate in critical temperature ranges and
prevent metal embrittlement during the formation of high-chromium martensite. During the work thermal cycles at the recommended normative documents of the welding modes were evaluated, and set the minimum heating temperature, which ensures the necessary mechanical properties of the weld metal and heat affected zone. According to the developed welding technology, control welded joints of pipes with a deposited layer of 12X13 steel were performed.

6. Results of experimental studies

The General view of the completed control welded pipe connections is shown in figure 1.

![Figure 1. Photos of the control of welded joints.](image1)

Nondestructive inspection of welded joints by methods of visual measurement control, radiation control methods, ultrasonic control of unacceptable defects of the seam and the heat affected zone did not reveal.

The study of the microstructure of the deposited layer showed that it has the structure of high-alloyed martensite, which provides high resistance to carbon dioxide corrosion (figure 2).

![Figure 2. Microstructure of the deposited layer of steel 12X13.](image2)

The absence of cracks and porosity in the deposited metal guarantees protection against the penetration of a corrosive medium to the inner surface of the pipe wall.
The study of the structure of welded joints showed that the filling and facing layers show the formation of a ferritic-perlite structure with a gradual transition to a high-alloyed ferritic-martensitic structure containing small chromium carbides at the root of the seam (figure 3).
Figure 3. Macro-and microstructure of the weld metal and HAZ of the welded joint.

The hardness measurements revealed that the weld has a higher level of hardness in the sections adjacent to the deposited layer (zone “b” in figure 3) and the metal of the reverse roller (zone “c” in
figure 3), which is associated with an increased share of the surfacing metal in these sections (figure 4).

Figure 4. Distribution of the values of the metal hardness of the seam and HAZ of the welded joint.

Tests of welded joints for uniaxial tension showed that the weld metal corresponds to the strength properties of the base metal of pipes. The impact strength of the weld metal and HAZ significantly exceeded the regulated requirements, both at positive and negative temperatures (table 2).

Table 2. Mechanical properties of control welds.

| Mechanical property | Temporary break resistance $\sigma_v$, MPa | Impact strength $KCU_{20}$, j/cm$^2$ | Impact strength $KCU_{40}$, j/cm$^2$ |
|---------------------|------------------------------------------|----------------------------------------|----------------------------------------|
| Requirement         | Not less than 470                        | Not less than 50                        | Not less than 30                        |
| Weld                | 477                                      | 227                                    | 167                                    |

Static bending tests were performed on the side of the facing layer. At a regulated bending angle of $80^0$, the samples withstood bending up to $160^0$ without cracking (figure 5).

Figure 5. Sample of a welded joint after a static bending test.

Since the corrosion resistance of the metal of the inner surface of the weld is provided by the alloying of the root layer during the melting of the deposited coating, and an insufficient degree of this alloying can lead to its significant reduction, the work was also conducted corrosion tests.

Comparative assessment of corrosion resistance was performed on samples cut from the root layer of the weld and the deposited metal. Corrosion tests were performed by holding samples in an autoclave at a fixed temperature of $+20\pm1.0\ ^{0}\C$ in a solution with a concentration of NaCl 4%, saturated with CO2 in the amount of 1000 mg/l and a pH value of 5, for 240 hours. Based on the test results, the weight index of corrosion was determined and the linear rate of corrosion was calculated. The test results are shown in table 3.
Table 3. The corrosion rate of the metal of the root seam layer and the deposited layer.

| Welded joint element      | Corrosion rate, mm / year |
|---------------------------|---------------------------|
| The root layer of the seam| 0.25544                   |
| Deposited layer           | 0.08713                   |

As can be seen from the data obtained, despite the restriction of the share of high-chromium metal deposited in the root layer of the seam, the corrosion resistance of the inner surface of the welded joint remains at a high level.

7. Conclusions

Based on the results of the work, the following conclusions can be drawn:

- studies of ring welded joints made according to the developed technology on 09G2S steel pipes with an internal deposited layer of 12X13 steel have shown the possibility of obtaining a corrosion-resistant welded joint with appropriate quality standards;
- regulatory requirements for the welded connection of pipes with an internal surfaced layer were defined, which can be used in the implementation of projects for the construction of field pipelines with this design;
- it was shown, that to provide normative values of mechanical properties of welded joints of pipes with internal weld layer requires the development of additions to existing welding technology to the preparation of pipes prior to welding and temperature control prior and concomitant heating, to avoid embrittlement of the metal of the root seam layer when its alloying.

References

[1] Markin A N, Nizamov R E 2003 CO2-corrosion of oilfield equipment p 188
[2] STO Gazprom 2-4 1-1135-2018 “Seamless casing and pump-and-compressor steel pipes of martensitic class, resistant to carbon dioxide corrosion. General specifications”
[3] Novikov S B, Rodomakin A N, Gumerov K M 2009 Problems of protection of welded joints of pipelines with internal coating and ways to solve them STJ “Problems of collection, preparation and transport of oil and petroleum products” (IPTER Issue 1 (75)) p 62-67
[4] Aiduganov V M Technologies for protecting pipe connections with coating from internal corrosion in the construction of oil and gas pipelines Territoriya Neftegaz No 1-2/04 p 44-47
[5] Motyakhov M A 1975 Electric arc welding of metals (Moscow: Higher school) p 232
[6] Meandrov L V 1970 Two-layer corrosion-resistant steels (Metallurgy) p 228
[7] Welding of dissimilar steels. Selection of electrodes, heating and tempering modes 1973 ed Zaks I A (L.: Mashinostroenie) p 208
[8] Steklov O I, Xu Shigo, Li Gaochao 1998 Welding technology of pipelines with double-sided enamel coating Welding production No 2 pp 29-31