The use of sprayed powders to create coatings in the welds of oilfield pipelines

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Abstract. The most damaged elements of oil field pipelines are welded joints, the life of which often does not exceed one or two years. The problem of anticorrosive protection of internal surfaces of welded pipe joints has not been solved to date. In this paper, the possibility of applying powder protective stainless coatings to the inner edges of the pipe adjacent to the annular weld is considered. The research of corrosion resistance and mechanical properties of pipe welded joints is presented.

1. Introduction
Field pipelines can be distinguished among the facilities most susceptible to oil production. Although the oil itself is not an aggressive medium, the presence of salts, chlorine compounds, oxygen, hydrogen sulfide, highly mineralized water in commercial oil products reduce the corrosion resistance of pipes, and the presence of highly abrasive particles in this substrate leads to the emergence and development of abrasive damage. Analysis of the actual service life of oil field pipelines in Western Siberia shows that corrosion and erosion defects reduce the service life of pipelines many times. Sometimes this service life does not reach even one year [1], and the main damage is concentrated in the areas of welded pipe joints. To reduce the effect of corrosion damage, several methods of protecting the metal of welded joints have been developed, aimed both at deactivating the corrosive environment and at creating protective devices that prevent contact between the corrosive environment and the metal surface. Corrosion inhibitors are used when carrying out measures to deactivate the transported product, but their use is not always technically justified, which is due to both the uneven distribution of the inhibitor along the length of the pipe and the need to periodically stop pumping during inhibition operations. Another way is to reduce the aggressiveness of corrosive products directly in the well, for example, by creating high rates of transportation of petroleum products in the "emulsion" mode to eliminate the product separation and isolation of aggressive components from it. The method of protecting the tread is widely used. There is also the method of using pipes with increased wall thickness, taking into account the increase in thickness "for corrosion", the method of creating the facing coatings of the inner surfaces of the pipes. Such coatings are made of relatively inexpensive and easily applied organic and inorganic materials, mainly based on thermosetting plastics and elastomers. Coatings can solve
the problem of protecting the base metal of the pipe from corrosion and erosion effects of the environment; however, having low heat resistance, they burn out or evaporate in the places of welding of pipes. At the same time, there are zones of increased corrosion defects in the pipeline - zones of welded joints, the number of which reaches one hundred pieces per kilometer of the pipeline.

The analysis of operability and damage of pipeline systems showed that there are several main mechanisms of damage of welded joints of pipe wires. The main danger to pipelines is general and selective corrosion in neutral aqueous media with pH 6-8, containing hydrogen sulfide and carbon dioxide, also contaminated with solid inclusions. The occurrence of damages manifested through the mechanism of corrosion-erosion wear and the development of corrosion defects according to the classical mechanism of electrochemical corrosion, which is enhanced by abrasive particles that constantly destroy the passive oxide layer on the metal surface, preventing the attenuation of corrosion processes. It is also possible to develop defects by the mechanism of sulfide stress cracking and hydrogen cracking.

2. Materials and methods

To date, almost the only method of protection of welded joints is the method of installation of protective sleeves installed during the assembly of the pipeline. The protective sleeve is a metal ring with anti-corrosion coating. Installing a protective sleeve allows you to achieve isolation of the weld zone from the pumped medium, to slow down corrosion processes. However, this method has a number of significant drawbacks, which include a decrease in the diameter of the pipeline, complicating the hydrodynamics of pumping products, complicating the technology of repair work, increasing the cost of installation work and the pipeline as a whole. Thus, we can state the fact that the problem of protecting the internal surfaces of welded joints of oil field pipelines has not yet been completely solved and remains one of the most pressing problems facing large oil companies. In St. Petersburg Polytechnic University together with STC developed a methodology and conducted research on the application of combined protective coatings consisting of a polymer coating of the base metal of the pipe and a protective ring of stainless steel in the weld zone. The width of the metal coating ring shall be guaranteed to exceed the width of the heat-affected zone of the annular weld, and the polymer coating shall be applied to the inner surface of the pipes in such a way that it overlaps the metallization zone outside the heat-affected zone of the weld. In this work, we studied the creation of protective metal coatings for welded pipe joints for field pipelines. In the work, we studied model objects-samples on pipes with a diameter of 109 mm and a length of 300 mm, made of steel 09Mn2Si.

It is known that metal coatings on the inner surface of pipes can be applied in various ways, by surfacing stainless wire in an inert gas medium, laser surfacing, plasma spraying of metal powder [2]. At the first stage of work, a preliminary assessment of each of the methods was carried out and the main advantages and disadvantages of each technology were studied. The advantage of surfacing in the argon environment was the technological simplicity of the process, the possibility of wide automation and robotization of the surfacing plant, the use of standard filler wires. The disadvantages include low quality (high roughness) of the surfacing surface - the inability to obtain an equidistant coating without additional machining, the complexity of quality control of the surfacing for the detection of pores and other micro-surface defects. These shortcomings, identified in the course of research, did not allow recommending the technology of surfacing in the application of metallization coatings, so the main attention was paid to the method of laser surfacing and plasma spraying. The advantages of the methods of plasma spraying and laser surfacing is that the resulting coatings provide a uniform layer thickness, the ability to adjust this thickness from the maximum at the end of the pipe and gradually decreasing as it moves away from the end, the relative ease of quality control of the coating. All this makes the methods of applying powder metallization coatings extremely attractive and can minimize the change in the internal diameter of the pipes in the transition layer zone, where a polymer coating will be applied to the metallization surface. A common disadvantage of these methods is the need to use metallic powders, usually used in additive machines, which have special requirements for the shape (spherical or approaching spherical shape of the particles, the absence or minimum number of
satellites, particles fused together when spraying the powder) and sizes from 60 to 160 microns, the absence of oxide films on the surface of powder particles, etc. The main drawback of these methods is the scarcity and high cost of the metal powder used for coating. Such powders are produced in very small volumes on the territory of the Russian Federation, and the purchase of imported powder is associated with a number of difficulties in its delivery and storage - due to the high chemical activity and the tendency to oxidation of fine powders. This leads to certain restrictions on the timing and volume of its use and storage. To reduce the cost of the metallized surfacing process, it is necessary to apply an integrated approach, when the surfacing complex includes not only a powder-coating unit, but also a unit for the production of such a powder. The presence of its own atomization system allows you to reduce the cost of powder, the cost of which is usually two to three times lower than the cost of small wholesale batches on the Russian market; to apply powders of different compositions at spraying, selecting own protective composition optimum for each aggressive environment; reduces to zero terms of delivery of powders, allows, on the one hand, to have, necessary technological reserve of the put material, with another not to create difficult warehouse systems on storage of powders. Ensuring the necessary requirements for the metal powder can be achieved by obtaining the powder by the melt dispersion method. Dispersion is the most productive, economical and efficient method of obtaining small and medium-sized metal powders-up to 70% of the volume of all industrial powders is obtained by this method [3]. It is widely used in the production of powders of multicomponent alloys-dispersion allows to achieve a uniform chemical composition of the composition, even when the content of alloying components above their solubility limit in the main component of the alloy. The powders obtained using the methods of dispersing the melts are spherical or close to spherical shape particles. For the production of metal powder from stainless steel, the method of plasma spraying of wire in a plasma atomizer developed and manufactured at St. Petersburg Polytechnic University of Peter the Great was used (figure 1).

![Figure 1](image1.jpg)

**Figure 1.** The atomization chamber of the plasma atomizer – a; the shape of the powder particles in the analysis using an optical microscope (Dav = 50 microns) – b.

Plasma atomization refers to gas atomization, when a metal drop melted in the arc of a plasma torch is sprayed by a jet of plasma-forming gas. As a plasma generator in a plasma atomizer, plasma torches with arc fixation by means of interelectrode inserts were used, which allow one to obtain an ascending voltage characteristic of the arc, providing stable operation of the plasma torches without ballast resistance in the power supply circuit from a source with a rigid characteristic. The atomizer makes it possible to obtain powders of spherical shape with sizes from 10 to 500 microns, the perfor-
mance of the atomizer depending on the chemical composition of the material, the required particle size and other requirements can vary from 1 to 5 kg of powder per hour.

3. Results and discussion

In the course of the research, the task of working out the technology of obtaining powder from steel 08Cr18Ni10Ti of spherical shape with particle sizes from 40 to 80 microns was set and solved. In the course of the research, the current strength from 150 to 250A, the velocity (flow rate) of the plasma-forming gas from 30 to 40 liters per minute, the wire feed rate from 0.5 to 5 meters per minute were taken as factors of variation.

The mathematical quasi-optimal plan of the second order was used in the work. Optimization of technological parameters of the spraying process allowed obtaining a spherical stainless steel powder (figure 1) with the retention of particles of specified sizes (in the total mass of the sprayed powder) of about 30%. The resulting powder was applied to the inner surfaces of samples of 109x7 mm pipes made of steel 9Mn2Si with a length of 150 mm. The surface for coating was prepared in advance – mechanically cleaned from the oxide film and degreased with organic solvents. The width of the coating was 50 mm, the thickness of the coating was -1 mm at the end of the pipe and 0.6 mm at a distance of 50 m from the end. After coating, the ends of the pipes were separated according to the standard technology according to GOST 16037-80 and welded according to the technology and modes used in the installation of oil field pipelines of Gazpromneft. In the process of welding, the root pass from the side of the protective coating brew stainless steel electrode brand Sv-04Cr19Ni9 (ER 308 LSi) and filling cutting was carried out with welding wire Sv-08Mn2Si (CITOFL 1). The resulting compound was cut into samples for metallographic investigations, mechanical and corrosion tests. Mechanical tests performed in accordance with GOST 6996-66, confirmed the quality of the welded joint—the destruction of samples after all tests occurred outside the weld zone, showing results that meet the requirements of GOST 32678-2014.

During visual inspection and metallographic studies, it was found that after welding of stratifications of the basic metal and the covering put by laser surfacing and plasma spraying, it is not revealed. Samples destroyed during mechanical tests did not have a clear reference of the origin and development of the crack. The most important tests of coated materials are bend tests [4]. Such tests were carried out on a breaking machine with the installation of a coated sample on supports and bending it around mandrels having a diameter equal to two, three and four times the thickness of the pipe of 14, 21 and 28 mm. The width of the sample was equal to twice the thickness of 14 mm, and the length of 200 mm. The bend was carried out at an angle of 90°. Two series of tests were carried out. In the first tests, the samples were bent so that the coating experienced tensile stresses, in the second – the coating experienced compressive stresses. The test results are shown in the table.

| Type of coating     | Corner bend 90° | tension on mandrel D, mm | compression on mandrel D, mm |
|--------------------|----------------|--------------------------|------------------------------|
| plasma spraying    | M, O           | M                        | M                            |
| laser cladding     | MM             | M                        | M                            |

* M – single microcracks, MM – numerous microcracks, O – detachment.

Thus, only in the conditions of a rigid bend on the mandrel with a diameter of 14 mm we found significant defects. On the mandrel with a diameter of 28 mm – no defects were found. On the mandrel with a diameter of 21 mm two microcracks were found on two of the five samples after plasma spraying and one of the five after laser surfacing. Such results may be considered satisfactory.
The tendency of the welded joint protected by metallization coatings to general corrosion was determined by conducting corrosion tests while holding samples in a corrosive medium (in a solution of 3.5% NaCl for 240 h). To assess corrosion resistance, samples were produced with a surface covering the base metal, weld and coating. The estimated characteristics were appearance and weight loss. The ends of the samples were insulated with a paint coating. Coating and welded joint were without insulation. It is established that after corrosion tests in the zone of protective metallization coatings, corrosion products and corrosion defects are completely absent. Extended loose corrosion products, ulcers up to 1.5 mm deep and up to 5 mm in diameter were found in the areas of the welded joint unprotected by the metallization coating (control samples).

4. Conclusion
According to the results of the tests, it was found that the protection of a welded joint by the coating applied by plasma spraying and laser surfacing fulfils its function in full. The powders obtained on the plasma atomizer provide the necessary shape and size of the particles. The proposed technology, after comprehensive tests on the experimental sections of pipelines, can be recommended for use in the assembly of field pipelines.

References
[1] Rodionova I G, Baklanova O N and Shapovalov E T 2005 Metallurgist 44-50
[2] Ermakov B S 2005 Technology of structural materials (SPb.: Institute of refrigeration and biotechnology Press)
[3] Ermakov S S and Ermakov B S 1996 Powder and composite (SPb.: SPbSTU Press)
[4] Yudin P E, Petov S M, Fedotova A V, Elistratova N V and Markov Yu M 2014 Pipeline transport 16-18