Influence of gas-powder laser cladding’s technological parameters on structural characteristics of corrosion-resistant steels’ restored surface layer

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Abstract. The results of the developed industrial technology for surface restoration of corrosion-resistant steels by laser surfacing are presented in the article. A comparative analysis of the microstructure of the welded wear-resistant layer, the fusion zone with the base material and the diffusion zone for different technological surfacing regimes are given. Dyrometric studies and non-destructive testing of the deposited layer for defects were performed.

1. Introduction
To protect metals and alloys from various types of external influences - wear, corrosion, high temperatures, static and dynamic loads, laser, plasma, electron beam, electric arc and other coating methods are used. Coatings combining a number of features are of great practical significance; for example, wear resistance, cavitation and corrosion resistance, which are important during the exploitation of such items as turbine rotors, electric motors, hulls and rods of heavily loaded pumps, compressors. Most often, the need for restoration and strengthening of this kind of parts is experienced by energy and oil-and-gas manufacturers of Orenburg region, such as Gazprom Dobycha Orenburg, Horizontal Drilling Center, Orenburg Drilling Company LLC, etc. Generally, mentioned products are the details of complex geometry equipment, performed from expensive complex alloy steels, more often imported, for which laser surfacing is an economically advantageous process in terms of material costs and recovery time.

The purpose of this study is to increase the operational durability of the energy and oil and gas production sectors by developing and implementing the optimal laser processing technology that provides the maximum combination of mechanical and operational properties.

2. Objects and methods of research
The method of laser surfacing with powder materials in a shielding gas environment is applicable for the restoration of worn or damaged surfaces of parts of the energy and oil and gas extracting industries in the conditions of "Technology" LLC in Orenburg, which specializes in the repair of a complex equipment. The development of the technology of restoration and hardening of the surface layer of products by the method of powder overlay welding was carried out on a robotic laser complex, figure 1, table 1, including:
- six-axis robot manipulator ABB IRB 4600 (Switzerland);
- rotator with adjustable speed for precise positioning of the part;
- powder dispenser, which regulates the rate of infusion of the deposition mixture into the laser radiation region;
- continuous ytterbium fiber laser LS-2 (OOO "NTO" IRE-Polyus", Russia);
- software allowing one to synchronize all the elements and work in automatic mode.

The equipment makes it possible to produce volumetric and local restoration, hardening of various shapes’ items, creating both single-layer and multi-layer powder cladding, obtaining a wear-resistant layer of specified thickness, structure and hardness for the different nomenclature products. The process ensures symmetry respectively for the direction of surfacing, high productivity, equality of rollers formation, high use factor of filler material.

By adjusting the ingredients of the compositions, it is possible to obtain fused layers with a hardness from 22 to 50 HRC.

![Figure 1. Laser surfacing complex.](image)

**Table 1. Parameters of the LS-2 laser system**

| Type                   | Wavelength, nm | Power, W | Laser generation mode | Hazard Class |
|------------------------|----------------|----------|-----------------------|--------------|
| Ytterbium Fiber Laser  | 1070           | 2000     | continuous            | IV           |

Based on the analysis of the recoverable materials nomenclature, which are the basis for surfacing, they are referred to two groups divided by the National Agency of Testing and Welding guidelines’ classifier. M04 - which includes chromium steels of martensitic and ferritic-martensitic grades of the 20H13, 30H13, 12H13 and 08H17 types, as well as the M11 group including austenitic heat-resistant steels of 12H18N10Т, 08H17N13M3Т types, table 2.

**Table 2. Restorable material groups and surfacing compositions**

| Melting materials group | Cladding Powder | Fraction, µm | Protective Environment        |
|-------------------------|-----------------|--------------|--------------------------------|
| 1                       | 2               | 3            | 4                              |
| M04                     | 6               | PR-30H13     | GOST 9293-74 (10-15%)          |
|                         | 20H13, 30H13    | PR-20H13N2   | gaseous nitrogen               |
|                         |                 | 40-100       | GOST 10157-79 (85-90%)        |
Based on the requirements for the structure, chemical composition and hardness of the surface layer, taking into account the composition and properties of the base material, variants of the surfacing compositions were selected to restore the worn surface layer, Table 3:

1) surfacing powder composition PR-20H13N2 with the size of the fraction (40-100 microns);
2) surfacing powder composition PR-30H13: PR-NH16 СР in the ratio of (3:1), which is a self-fluxing powder mixture with the size of the fraction (40-100 microns);
3) surfacing powder composition PR-20H13: PR-NH15 СР2 in the ratio of (1:1), with the size of the fraction (40-100 microns).

| Powder Composition | Chemical Composition, % (by weight) | Parameters |
|--------------------|------------------------------------|------------|
| PR-20H13N2 base    | 0.23 12.87 2.18 0.70 0.68          | 40-100     |
| PR-30H13 base      | 0.34 12.83 0.27 0.48 0.60           | 40-100     |
| PR-NH15CR2 base    | 3.7 0.50 14.7 base 3.10 -            | 40-100     |
| PR-NH16CR3 base    | 4.94 0.71 15.6 base 3.13 -           | 40-100     |

It is known that such compositions are used to produce coatings which are resistant to corrosion, wearing by friction and abrasive particles [1].

For detailed study of the laser recovery and hardening process, optimization of the equipment operation, increasing the productivity and versatility of the process, working out the technological parameters of surfacing (the rotation speed, the flux of the buildup composition, the degree of overlapping of the rollers during surfacing, power and focusing of laser radiation) was carried out using mathematical statistics methods, on the basis of which a mathematical dependence of the output values (microhardness, hardness, thickness of the deposited layer) on the parameters of the technological process. At the stage of the matrix realization, the witness samples were obtained for the control of which optical, electron microscopy and micro-X-ray spectral analysis methods were used, which allowed one to further understand the nature of the phases and hardening mechanisms formed in the deposited layer and in the thermal effect zone [2].

The studies were carried out using the Nikon ECLEPSE MA100 optical microscope and the JEOL JSM-6460LV electron microscope with the attachment of the energy dispersive analyzer INCA energy.
The hardness of the metal was determined on a stationary hardness tester HVS-10 with an error of ± 5 MPa by the Vickers method. Microhardness was determined on a PMT-3 device with a load of 100 g increments of 0.1 mm.

3. Development of laser welding technology

Analysis of laser surfacing methods made it possible to determine that deviations from the established technological parameters lead to such defects as cracks, pores, understatement, hardness failures, coating peeling and cracks after machining, which are identified by visual and ultrasonic inspection methods, defectoscopy, hardness measurement, metallography.

A promising area for laser surfacing is the use of composite materials containing 20-35% of the hardening carbide phase, which, according to the studies, is the optimal composition for the operation of coatings in corrosive environments, combined loading and wear [1].

When laser surfacing, depending on the modes of laser action, the thermophysical characteristics of the surface layer and the base material, as well as the structural state of the deposited and processed materials, various processes of structure formation are possible. Simultaneous action of many factors such as formation and dissolution of carbides, saturation of the matrix with doping components, martensitic transformation, microchemical heterogeneity and other processes make it difficult to predict the properties of the finished product and lead to the need for studies of the structural state of the weld layer, the transition diffusion zone and the fusion zone with the base metal.

The microscopic analysis of the deposited layer for two variants of surfacing has been performed (figures 2 and 3).

The microscopic analysis of the deposited layer and the fusion zone with the 20H13 grade basic metal shows that the structure of the surface layer is a martensite with uniformly distributed carbide inclusions, such as (Cr,Fe)\textsubscript{23}C\textsubscript{6}. Closer to the fusion zone, a structure consisting of elongate columnar crystals having an irregular shape and a growth direction corresponding to the heat sink and proportional to the temperature gradient is observed. The structure of the base is formed by crystals of a ferrite-cementite mixture and small particles of carbide (Cr,Fe)\textsubscript{23}C\textsubscript{6}, a transition layer that differs sharply from the parent metal, but does not form; the fusion boundary can be seen in micrographs, Fig. 2.

Figure 2. Metallography of the surface layer during laser surfacing on 20H13 grade steel

The advantage of surfacing with the powder PR-20H13N2 has a low tendency to cracking, however, such surfacing material does not give high corrosion resistance in the hydrogen sulphide environment under load, and therefore it became necessary to test the second, more complex
composition of the surfacing composition PR-30H13: PR-NH16SR3 in the ratio of 3:1, which is a self-fluxing iron-nickel alloy. Such coatings are resistant to gas corrosion up to temperatures of 700-850° C, withstand fresh and sea water, salt solutions, oily media, ammonia and other corrosive environment.

The main structural phase of the deposited layer with composition 2, Fig. 3, is a $\gamma$-solid supersaturated solution based on nickel and strengthening phases: chromium and nickel borides of variable composition, chromium carbides such as $\text{Cr}_2\text{C}_6$ and chromium carboborides; In addition, there are particles of a stronger $\text{Cr}_7\text{C}_3$ carbide. Boron and silicon form fusible eutectics with nickel with a melting point of 950-1080°C, and also reduce oxide films on the surface of the substrate with the formation of borosilicate slags (self-fluxing).

![Figure 3. Metallography of the surface layer during laser surfacing on steel 30H13 composition of the 30H13 surfacing mixture: PR-NH16CR3](image)

This phase composition of the deposited surface layer is characterized by the absence of phase transformations upon cooling in the temperature range from 960 to 20 °C, while the phase transformations, occurring in the iron-carbon system with a change in volume in the base metal, create the risk of cracking the coating on steel and cast iron substrates upon cooling. In addition, a microanalysis of the structure of this overlay has shown the presence of a transition diffusion zone with a more complex crystalline structure, and consequently an increased hardness and a low adhesion affinity to the basic metal.

The results of the distribution of microhardness over the thickness of the welded layer corresponding to 1.10 and 1.36 mm are shown in Fig. 4. The hardness of the welded layer is in the range 400-460HV, which corresponds to the hardened structural state and does not cause any difficulties in machining, this kind of surface restoration. A slight increase in the microhardness in the heat-affected zone (HAZ) of the microhardness to a level of 431 HV is explained by the formation of a more complex crystal structure of the transition diffusion zone. Then a regular change follows in the microhardness of the metal substrate to 270-300 HV.
Figure 4. Hardness distribution over the thickness of the deposited layer on 30H13 steel. 
a) - the thickness of the deposited layer; b) - distribution of microhardness over weld zones

Practice has shown unsatisfactory operational resistance of products welded with composition 2, due to the low adhesion resistance of the coating due to the difference in the structural classes of the coating and the base metal, as well as the formation of a transition layer with a high hardness and, as a consequence, deteriorating adhesion resistance. These factors led to the need for further development of the laser recovery process in order to obtain a reliable coating that has both high wear and corrosion resistance.

Having studied the problems of surfacing of dissimilar compounds, taking into account the propensity of self-fluxing compounds to crack formation during cooling, an experimental technological process for surfacing austenitic grade steel 12H18N10T with the 20H13N2 surfacing composition was proposed: PR-NH15SR2.

The technological process included pre-heat treatment of the product before surfacing (annealing to relieve stresses and leveling the base metal in the temperature range 600-650°C, preheating the article prior to surfacing to a temperature of 300-350°C, followed by slow cooling of the deposited layer with a change in the ratio of the powder composition 20H13N2: PR-NH15CR2 in the ratio of 1:1. In addition to the technological parameters, the parameters of the laser unit were adjusted, increasing the laser power up to 1900, the deposition rate up to 20g/min, with reducing the powder supply to the melting zone by 15%, trying to reduce the height of the roller during surfacing. With the implementation of this technology, it was possible to obtain the following results: on the prototypes, microanalysis showed the formation of a more dispersed structure, the eutectic does not have pronounced dendritic branching of the surface layer crystals, 1000 times it is seen that the branches of dendrites are of rounded shape and fragmentary structure, figure 5.
Figure 5. Metallography of the surface layer obtained by laser deposition on 12H18N10T steel. a - structure of the deposited layer; b - the structure of the surface and diffusion zones

Microanalysis of the structure of this variant of surfacing showed the presence of a transition diffusion zone having a smaller width and is characterized by an inhomogeneous diffuse structure, the fusion boundary is practically not visible in microphotographs; a transition layer sharply differing from the base metal is not formed.
The distribution of the microhardness values over the fused layer and the heat-affected zone, Fig. 6, shows the increase in surface hardness by 20-30% due to sufficient time with slow cooling to form more complex compounds of carbide phases. Non-destructive testing by ultrasonic and color flaw detection methods, VIC and hardness measurement showed the formation of a defect-free high-alloy coating with a hardness of 50 ... 55 HRC.

4. Conclusions

The technology of laser surfacing with powder materials in the environment of shielding gases of pump and compressor equipment parts has been put into production execution in the conditions of the enterprise LLC "Technology", Orenburg, on the laser processing section of metals in the integrated shop since June 2016 when restoring worn rotor shaft No. 46.7020 .000 (order №02.16.100) made of imported material, identified as H15N40M5D3T2VBJF and formerly used in conditions of aggressive hydrogen sulphide-containing media at the facility "Gazprom mining Orenburg" LLC. The basis for the execution of the order by laser surfacing was the terms of reference for the partners of OOO Tekhnologiya represented by DKS-1 (booster compressor station) of Gazprom Dobycha Orenburg. The terms of reference included requirements for cleanliness, wear resistance, corrosion resistance, hardness, accuracy of compliance with geometric dimensions, which was taken into account in the development and implementation of laser recovery technology [3].

The main technical characteristics of the development, its principal differences from existing analogues: are included in the development of the standard for the organization of the STO SMC 7.5-04.2016 (date of introduction is 07.09.2016) "Laser surfacing with powder materials in the environment of shielding gases of parts of pump and compressor equipment". The technology of laser surfacing with powder materials in the environment of protective gases of pump and compressor equipment parts is certified in accordance with the requirements of the National Agency for Welding Control (NAKS) for the restoration of facilities subject to control by the Federal Service for Ecological, Technological and Nuclear Supervision (Rostekhnadzor).

References

[1] Grigoriants A G, Shiganov I N, Misyurov A I 2008 Technological processes of laser processing. Grigoriants and others (Moscow, MSTU, N.E. Bauman)

[2] Krylova S E, Semka Ya S 2016 Influence of technological parameters of laser surfacing on the structural characteristics of the reconstructed surface layer. Ural school of young metal
scientists: a collection of materials and reports of the 17th International Scientific and Technical Ural School- seminar of metal scientists - young scientists. (Ekaterinburg)

[3] Krylova S E, Oplessin S P, Yasakov A S, Strizhov A O 2017 The technology of laser surfacing with powder materials in the environment of shielding gases of parts of pump and compressor equipment. Laser technological complexes and technologies for the processing of industrial materials. Bulletin of LAS 25