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PECULIARITIES OF TECHNOLOGY OF REPAIR WELDING OF HPP TURBOUNITS AFTER LONG-TERM OPERATION

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Long-term operation of turbine equipment promotes formation of cracks in the casings of valves, cylinders and steam lines under effect of various factors. Their appearance is caused to the significant extent by deterioration of structure and mechanical properties of metal. Aim of the work is the analysis of possibility to take into account the state of metal in a damaged part in the technology of repair welding for providing a reliable operation of welded joint. Review of literature showed that modem technologies of repair welding envisage technological measures for prevention of cold crack formation, but do not account for deterioration of base metal state and its effect on workability of the welded joint. Removal of damages in turbine equipment components after long-term operation require development of new technologies of repair welding using additional technological measures of thermal and deformation influence. 24 Ref., 1 Table, 2 Figures

Keywords: *components of turbine equipment, cracks, heat-resistant steel, structure, metal state, welding repair technology, technological measures*

A significant number of emergency stops of HPP units is caused by damage of stop and control valves, cylinders of pressure and steam pipeline, which are among the main components of turbine equipment [1]. The casings of valves and cylinders represent large-sized thick-walled cast parts of a complex structure of heat-resistant steels Cr–Mo or Cr–Mo–V and have, as a rule, welded joints with branch pipes of steam lines. Their service conditions are characterized by high operating temperatures (545 ° C) and steam pressure (23.5 MPa). The service term of some of them has already amounted to more than 320 thou h, which significantly exceeds the estimated (100 thou h) and fleet (220 thou h) life. A high service life of the parts is predetermined by the considerable «durability» of the metal, successful structure as well as repair with the use of welding for the serviceability restoration in case of damages [2, 3].

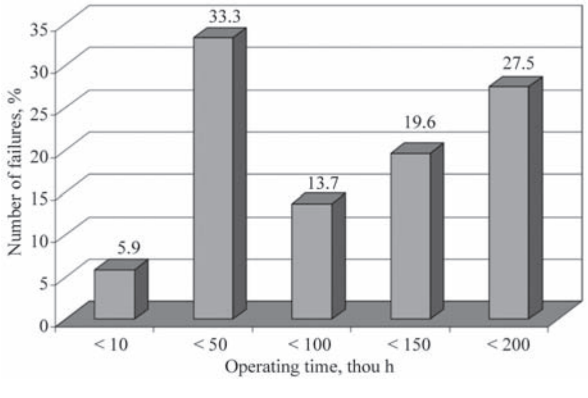

Figure 1. Number of failures in the HPP equipment, depending on the service life [4]

The most frequent type of damage to casing parts are cracks, and the place of their occurrence is welded joints [3]. They can be formed in different periods of operation under the action of technological, structural and operation factors [3, 4] according to the mechanism of cold brittleness (cold cracks) [5]; fatigue or corrosive fatigue fracture [2], dispersion embrittlement (cracks of reheating) [3, 6], creep [2, 3, 7]. Damage to equipment elements in the period from 10 to 50 thou h is predetermined by the defects of metal and assembly. The number of failures increases with the increase in operating hours (Figure 1). The main factor causing their increase is the deterioration of the metal structure and properties.

The cracks of cold brittleness are formed after operation of a period being less than 5 thou h and the cause is mainly a technological factor, i.e. violations or drawbacks of technology of welding, heat treatment and manufacturing of castings, from which the defects, the structures of quenching, hydrogen saturation of the metal, high levels of stresses were formed in the metal. During this period, the mechanical properties of the metal vary slightly, but the parameters of resistance to fracture, sensitive to local structural changes, decrease. After 5–20 thou h, the cracks from the dispersion embrittlement of metal can be formed after reheating as a result of welding, unsuccessful heat treatment mode or in the non-heat treated joints at the operation temperatures being higher than 510 °C [4, 5]. The precipitation of carbides both over the body and along the grain boundaries, leads to a decrease in cracks initiation [2, 8].

The fatigue cracks initiate after 20–70 thou h under the influence of high cyclic stresses resulted from non-stationary mode of service, corrosion effect of the operating environment and the presence of stress concentrator. A deformation of the material under thermal influence is propagating by the mechanism of active tension-compression. At this period, the major changes in the metal structure occur at the level of redistribution of carbide components with the formation of a substructure, favourable for crack propagation [6].

The creep cracks can be formed from the arising of high long-term stresses, exceeding the design ones under the influence of each or in a complex of three factors: technological, structural and operational and are recognized as one of the main causes of damaging steam lines at the temperatures higher than 450 °C [2, 3]. The development of creeping process occurs primarily at the reduced resistance to counteracting a long-term stress at a high temperature due to insufficient working section of a part, degradation of structure and action of corrosive environment [1, 9]. At the increased pressure and service life, the factor of degradation of the structure becomes the most frequent cause of arising cracks. The characteristic of changing the structure, causing degradation, is a gradual transformation of the ferrite-pearlite (steel 12Kh1MF) or the bainite-ferrite structure (steel 15Kh1M1F) (Figure 2, *a*) into ferrite (Figure 2, *b*) with the coarsening and formation of the carbide clustering along the grain boundaries, as well as the appearance of pores and creep microcracks [6, 9]. At the same time, a significant change in the mechanical properties of the metal occurs in relation to the level of these characteristics for delivery conditions [10]. A part of steel 15Kh1M1FL is rejected if there was a decrease in the yield strength to 270 MPa, ultimate tensile strength to 470 MPa and impact toughness to 130 kJ/m^2, as well as if the creep pore chains appear along the grain boundaries during examination at the microscope magnification of ×500 [11].

For repair of parts of the power equipment, consumable electrode arc welding is used [12, 13]. Development of the technology of welding is carried out for each repair, its method and technique of performance, welding mode, welding consumables, need in additional technological measures of thermal and deformation influence for producing welded joint, equal to the base metal, are determined. The main provisions of the welding technology and the peculiarities of its application are determined on the basis of the requirements of the regulatory documents, depending on the initial parameters, such as: chemical composition and hardness of the base metal, dimensions of damage, regions of its location and of a part in general, operating conditions, etc. There are no recommendations for taking into account the service life and at the same time changing the structure and mechanical properties of the metal. The initial structure significantly influences the weldability of the base metal, the resistance to cracking and the properties of welded joints [5, 14] and its change should be taken into account while choosing or developing a repair welding technology.

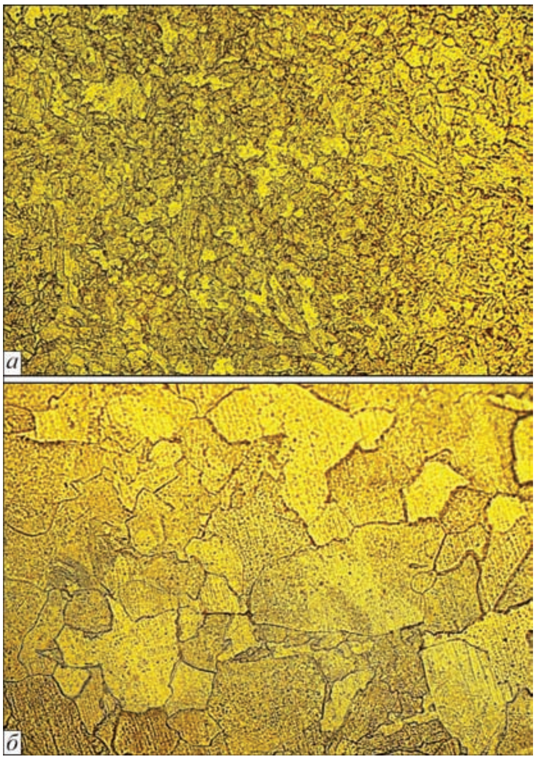

Figure 2. Microstructure (×500) of metal of branch pipe of the stop valve in the condition: *a* — before operation; *b* — after operation at the temperature of 560 °C, and pressure of 230 MPa, of 310 thou h duration (*b*)

The aim of the work is to analyze the possibility of taking into account the state of the part metal after long-term operation in the technology of repair welding to provide a reliable service of welded joint.

Many technologies of repair welding of parts of heat-resistant steels are known [15, 16]. One of the very first technologies, which found a wide application for repair welding of large-sized massive parts, is welding using austenitic electrodes [17, 18]. It allows preventing the formation of cold cracks in welded joints without preheating and postweld heat

Recommendations on using technological means in welding depending on base metal condition

Condition of welded metal	Technological measures of welding							
	Welding method	Welding materials	Welding mode	Preheating	Deposition of surfacing layer	Peening of deposited layers	Thermal rest	High-temperature tempering
Cold brittleness	+	+	+	+	+	+	+	+
Dispersion hardening	–	–	–	–	–	–	–	–
Thermal fatigue	–	–	–	–	–	–	–	–
Creep	–	–	–	–	–	–	–	–
Recommendations: + — present; — absent.								

treatment, which is important for implementation of disassembly-free repair. The disadvantage of such technology is the embrittlement of metal in the fusion zone of austenitic metal with pearlite steel because of the formation and propagation of chemical and structural heterogeneity at a high temperature, which is caused by carbon diffusion [19]. Delamination of austenitic weld with a chemical composition based on iron is carried out after 4–8 years of operation, and based on nickel — after 15–20 years of operation. The term of destruction of a welded joint with austenitic high-nickel weld can decrease to 3–4 years, if a part was in service for over 150 thou h before repair [16]. To prevent the embrittlement of the fusion zone of an austenitic weld with pearlite steel, the operation of such welded joints is limited to 480 °C [18].

The main method for elimination of defects in the casing parts of the power equipment is the manual arc welding using pearlite electrodes with preheating and postweld high-temperature tempering [13, 16]. The improvement of reliability of welded joints is achieved by bringing the structure of the metal into equilibrium state, reducing the level of welding stresses and diffusion hydrogen. However, an increased heat input contributes to the growth of grain and chemical heterogeneity, which will promote reducing the crack resistance to in degraded structure of base metal. Therefore, the welding conditions, temperature of preheating and postweld heat treatment at such a method are subjected to mandatory correction depending on the service life and condition of the metal of a part, which is subjected to repair.

The relatively new welding technologies with pearlite electrodes using of technological methods for control of thermodeformational welding cycle are known, for example, such as: technique of forming a weld using the «transverse hill» method [20]; application of low-temperature thermal rest instead of high-temperature tempering [21–23]; preliminary surfacing of edges welded [16], application of the minimum energy input and technique of welding by narrow annealing beads applied in a definite sequence; layer-by-layer peening of weld metal [16, 24]. A high resistance of welded joints to crack formation in these technologies is achieved due to a more efficient use of welding heating, preventing the formation of coarse grain and brittle structures in the near-weld zone, reducing the level of stressed state and the content of diffusion hydrogen in the metal. The greater opportunities for improving the structure and properties of welded joints make them challenging for using in repair of components of power equipment, having a long service life. But there are not so many technological measures, applied in these technologies and their parameters are not determined for repair of parts with different conditions of metal welded (Table).

Thus, taking into account the diversity of types and sizes of components of power equipment, operating conditions, type of damages and condition of metal during their repair, a specific welding technology should be applied. Determining its optimal parameters requires additional investigations, the relevance of which grows because of the further increase in the service life and degradation level of metal. The development and application of welding repair technology is an economically and organizationally effective measure, which provides a significant elongation in the service life of parts without significant financial costs as compared to replacement for the new ones.

Conclusions

1. The damages to the components of turbine equipment are formed in different period of operation under the influence of many factors and are always accompanied by the preliminary deterioration in the structure and properties of the metal.

2. The modern technologies of repair welding do not take into account the condition of the metal of a damaged part, which does not provide confidence in the reliability of the produced welded joints.

3. The elimination of damages of components of turbine equipment after a long-term operation requires the development of new technologies of repair welding with the use of additional technological measures of thermal and deformation influence.

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