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RESTORATIVE HEAT TREATMENT OF STEAM PIPELINES AND THEIR WELDED JOINTS (REVIEW)

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The state and key directions of development of technologies for restorative heat treatment of steam pipeline welded joints are considered. The technologies of heat treatment and their advantages and disadvantages are presented. The first part of the review presents a summary of the development of restorative heat treatment. The directions of development of restorative heat treatment of welded joints, the most promising for extension of service life of steam pipelines according to the opinion of the authors, were formulated and justified. The justification of the possibility of using heat treatment of long-operating elements of steam pipelines with a degraded structure and presence of damages is given. The possibility of producing a metal of a steam pipeline with a structural state and properties, meeting the service requirements is justified. 23 Ref., 3 Figures.

Keywords: *restorative heat treatment, steam pipeline, welded joints, metal structure, operation, damageability*

Structural changes, taking place in the metal of steam pipelines of heat-resistant pearlite steels 15Kh1M1F and 12Kh1MF, operating for a long time under creep and low-cycle fatigue, lead to a decrease in its properties and a reduction in the service life. Welded joints of steam pipelines are characterized by the presence of a certain structural, chemical and mechanical heterogeneity, formed as a result of welding heating. The presence of heterogeneity provides a greater intensity of structural transformations in the metal of welded joints as compared with similar transformations of the base metal of steam pipelines. Accordingly, the service life of metal of welded joints of steam pipelines is limited by structural transformations, taking place in their metal.

During the long process of operation of steam pipelines (more than 250 thou h) under creep conditions, their initial structure, recommended by standard documentation [1–3], turns into a ferrite-carbide mixture. At the same time, the metal is damaged by creep pores and fatigue cracks. Structural changes in the metal of the heat-affected-zone (HAZ) regions of welded joints, as well as its damageability, occur with the greater intensity than similar changes and damageability of the weld metal and base metal. Structural changes and damageability are more typical to certain HAZ regions of welded joints of steels 15Kh1M1F and 12Kh1MF [4, 5]: partial recrystallization, where the new products of austenite decay present a globular pearlite (Figure 1); overheating, where the number of austenitic grain is less than 5^{th} (GOST 5639–82); fusions, where relatively large ferrite grains can be formed, grouped in chains, arranged symmetrically to the weld metal (Figure 2).

In connection with the constantly increasing number of steam pipelines having a degraded structure, as well as a certain degree of damageability, it is important to use a restorative heat treatment (RHT) to extend their service life [7–13]. The use of RHT can provide restoration of the degraded structure and properties to a level close to the initial state, as well as eliminate the damageability, formed by the creep mechanism.

The aim of the work is to clarify the possibility of using RHT for long-operating elements of steam pipelines with different degree of degradation of the structure and a certain level of damageability, to obtain their structural state and properties, which meet the operational requirements.

Replacement of steam pipelines, having a degraded structure and damages, by new ones, is a very laborious and expensive operation. In some cases, such an operation can be prevented by using local RHT. When performing RHT, it is necessary to take into account the peculiarities of the distribution of stresses formed during releasing the support-suspension system [14].

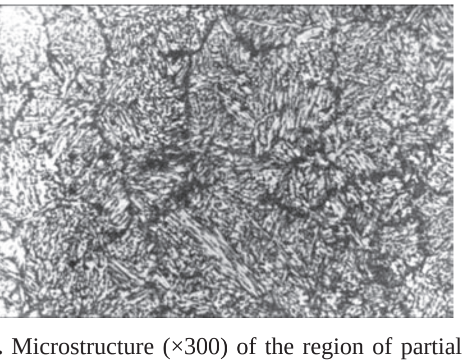

Figure 1. Microstructure (×300) of the region of partial recrystallization of HAZ metal of welded joint of steel 15Kh1M1F [6]

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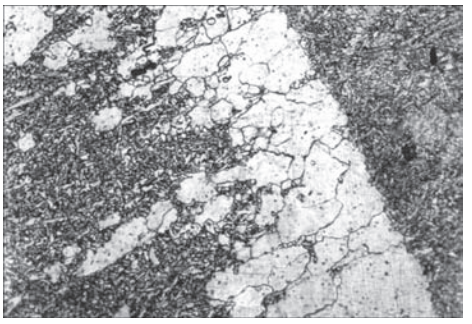

Figure 2. Microstructure (×100) of the region of fusion of the HAZ metal of steel 15Kh1M1F [5] welded joint

To optimize the performance of RHT, it is advisable to consider the features of structural changes, occurring in the metal of steam pipelines, operating for a long time under creep conditions. The transformation of the initial structure into ferrite-carbide mixture provides physical and chemical processes, taking place at different intensity in the metal of HAZ regions of welded joints and at a constant (less intensive) one in the weld metal and in the base metal of the steam pipelines. Physicochemical processes can be represented by the sequence of passing their stages [15–17]: diffusion movement of chromium and molybdenum from central zones of α-phase crystals to their near-boundary zones, which leads to the formation of segregations; transition of chromium, molybdenum, and vanadium from crystals of α-phase into carbides, as well as the formation of new carbides of group II (Mo_2C and VC); running of carbide reactions $M_3C \rightarrow M_7C_3 \rightarrow M_{23}C_6$; coagulation of carbide phases, mainly $M_{23}C_6$ and M_7C_3; formation of discontinuous chains, mainly from carbides $M_{23}C_6$ along the grain boundaries of α-phase; formation of polygonal structure (areas of overheating and partial recrystallization of HAZ); local elimination of grain boundaries (initial stage of recrystallization); coalescence of vacancies, nucleation and development of creep pores; separation of grain boundaries from carbides; initiation and propagation of fatigue microcracks.

Operation of power units in the maneuverable mode is characterized by the presence of variable (cyclic) stresses, as well as the presence of local regions of their concentrations. For example, in backing rings of joints, being butt welded; in places of contact of steam pipelines of different thicknesses; in the region of HAZ fusion (inner surface of steam pipeline); in places of lacks of penetration, lacks of fusion along the walls of a gap, etc.

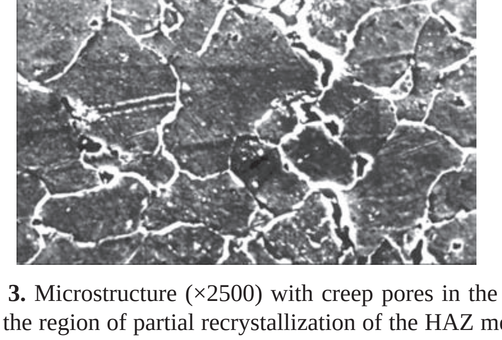

Figure 3. Microstructure (×2500) with creep pores in the structure of the region of partial recrystallization of the HAZ metal of steel 15Kh1M1F [21] welded joints

Structural changes lead to a decrease in strength and impact toughness of the metal of steam pipelines. In the process of long-term operation under creep conditions, deformation processes occur, which are interconnected with structural transformations, for example, such as formation of a subgrain structure, increase in the density of dislocations near obstacles, etc. It is known that deformation processes are associated with the formation of creep pores [18], which requires further clarification.

In the process of RHT (normal mode), the pores, having a diameter of less than 2 mm, are eliminated (healed) [7–13]. It is noted that in the presence of accumulation of damageability of higher than 20–25 % of the state of fracture, applying RHT, heat resistance of the elements of steam pipelines increases insufficiently. The healing of pores as a result of diffusion of substitution and interstitial elements occurs under the influence of the following factors: temperature of isothermal exposure in the austenitic state; exposure duration; polymorphic transformations. It is advisable to reveal the shape and limiting dimensions of creep pores and fatigue cracks, which can be eliminated using RHT.

The double normalization proposed by P.A. Antikain [19, 20] deserves attention: the first one is at a temperature of $T \geq 1050–1100$ °C, which provides elimination of relatively large pores and homogenization of γ-phase; the second one is at the temperatures recommended by standard documentation and used for treatment of steels in the initial state, which allows increasing the number of austenitic grain.

High-temperature cyclic thermal treatment (HCHT), which provides a multiple cyclic heating above the temperature of polymorphous transformation and subsequent cooling, requires clarification. It is also advisable to study the peculiarities of healing pores located over the body and along the boundaries of α-phase grains, as well as to clarify how healing of pores is associated with the segregation of chromium and molybdenum.

Heating and corresponding exposure above the critical point A_{c3} provides the decay of carbides of I and partially II groups. The reverse transition of alloying elements of chromium, molybdenum and vanadium occurs from carbides into crystals of the α-phase.

It is advisable to clarify: how the exposure at the temperatures above A_{c3} is associated with the austenitic grain size; influence of the exposure duration on the homogeneity of austenitic grains, i.e., the uniform distribution in the γ-phase of the substitution and interstitial elements; how the heat treatment provides elimination of creep pores, having a rounded and branched shape, shown in Figure 3; effect of RHT on fatigue cracks.

A considerable practical interest is represented by restorative heat treatment of welded joints. As is noted above, the structural transformations and damageability of welded joints occur most intensely in the regions of fusion, overheating, and partial recrystallization of their HAZ [4, 5].

The metal of the region of partial recrystallization is subjected to welding heating during manufacture of joints in the temperature range of A_{c1}–A_{c3}. The region can have a lower hardness than in the other regions of HAZ, as well as weld metal and base metal. During long-term operation of welded joints, the hardness of the region of partial recrystallization decreases to a greater degree than the hardness of other HAZ regions, as well as that of weld metal and base metal [6, 18, 21]. The structure of the partial recrystallization region can represent the globularized pearlite as a rejection component [4, 5]. Double RHT, as well as HCHT, provide a more complete elimination of rejection structures and damageability, caused during welding in the HAZ, as well as in the weld metal regions [7–15, 22, 23]. Double normalization and tempering [8] deserves attention when using heat treatment, which provides the possibility of relatively complete elimination of structural, chemical and mechanical heterogeneity, as well as dispersion strengthening of welded joint metal. It is urgent to establish the possibility of induction heating during heat treatment of steam pipelines, including their welded joints without dismantling the steam pipelines themselves. The improvement of heat treatment of steam pipelines, having a degraded structure and a certain level of damageability, will allow obtaining the structural state of their metal and properties, meeting the operational requirements, which will provide an increase in their service life.

Conclusions

It was found that for introduction of restorative heat treatment of metal of steam pipelines and their welded joints, having a degraded structure and a certain damageability, it is necessary to investigate:

• effect of heating on the value of austenitic grain;

• relationship between the heating and homogeneity of the austenitic structure, as well as dependence of structural state on heating;

• possibility of elimination of creep pores of a certain size and shape applying heat treatment.

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