FEATURES OF DAMAGEABILITY OF STEAM PIPELINE WELDED JOINTS BY THE CREEP MECHANISM

V.V. DMITRIK and **S.N. BARTASH**
Ukrainian Engineering Pedagogic Academy, Kharkov, Ukraine

Considered are the features of damageability of long-term operating welded joints from heat-resistant pearlitic steels by the creep mechanism. It is shown that damageability of welded joints is a three-stage process, and essentially depends on metal degradation, which is controlled by physicochemical processes occurring in welded joint metal.

Keywords: *arc welding, heat-resistant pearlitic steels, steam pipelines, welded joints, corrosive environment, creep, damageability, physicochemical processes*

High-pressure welded steam pipelines manufactured from heat-resistant pearlitic steels 15Kh1M1F and 12Kh1MF function under the creep and low-cycle fatigue conditions in corrosive environment for a long time. The main constituents of fracture of welded joints are creep, fatigue and fatigue-corrosion cracks and their formation mechanisms have a significant difference [1–4]. Also one of the types of fracture is corrosion damageability. Its role increases during a long-term running of welded joints. From our point of view, an influence of mentioned above constituents on damageability of welded joints should be considered separately for general evaluation of metal degradation.

The purpose of present paper is to specify the features of damageability of long-term operating welded joints of steam pipelines from heat-resistant pearlitic steels by the creep mechanism.

Plastic deformations, a level of which locally can make from 0.5 up to 8.0 % [2], are accumulated in the welded joint metal in the process of running. Creep cracks are formed from the outside of long-term operating welded joints and further crack propagation occurs deep into metal (Figure 1). Such cracks are generated, mainly, along a fusion area or area of incomplete recrystallization of HAZ metal [1, 2, 5, 6]. However, their formation is also noted over the deposited metal in welded joints of steam pipelines with a life time above 200,000 h. A rate of crack propagation significantly depends on structural, chemical and mechanical inhomogeneity of welded joints [2, 6–8] and cracks have, mainly, brittle intergrain character (Figure 2). The presence of structural inhomogeneity provides different intensity of physicochemical processes occurring in the metal of long-term (> 200,000 h) operating welded joints. Volume diffusion of atoms of chromium, manganese, silicon and phosphorus into a thin near-boundary area of grains of α-phase [9], grain boundary diffusion, dislocation displacement by means of creeping and sliding, polygonization of grains of α-phase, $M_3C \rightarrow M_7C_3 \rightarrow M_{23}C_6 \rightarrow M_6C$ carbide reactions, and formation, displacement and coalescence of microdiscontinuities can be referred to such processes. The greatest intensity of such processes is characteristic of structures, classified as rejected or close to them.

From our point of view, a list of rejected structures should be enlarged. Structures consisting of grains of α-phase (Figure 3) with $l/n > 2$, where l is the grain length, and n is the width of grain from 15 μm and more, should be referred to them. Such structures form during welding under higher conditions, for example, in mechanized welding of joints 60 mm thick in $CO_2 +$ + Ar atmosphere with 400 A current. The level of intensity of grain-boundary and volume diffusion will

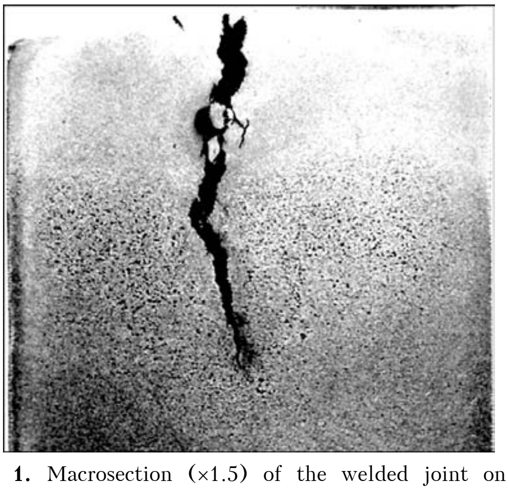

Figure 1. Macrosection (×1.5) of the welded joint on steel 12Kh1MF with creep crack in the weld metal (live steam pipeline, 190,000 h running)

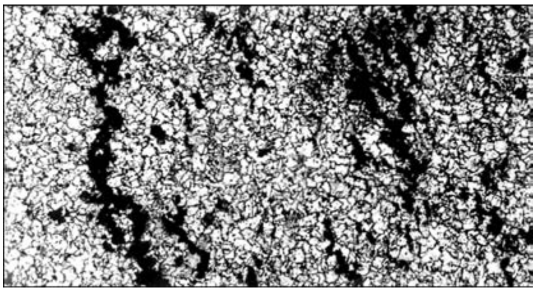

Figure 2. Microstructure (×100) of metal of area with incomplete recrystallization of HAZ of welded joint on steel 12Kh1MF of direct steam pipeline (third stage of damageability, 210,000 h running)

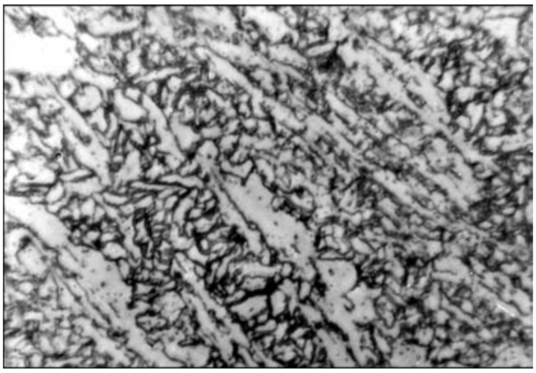

Figure 3. Microstructure (×600) of weld metal of 09KhMF type alloy with elongated grains of α-phase (base metal is steel 15Kh1M1F)

be significantly different under the conditions of anisotropy and cubic singony of grains of α-phase as well as various stage of activation. The presence of grains of elongated shape due to increased intensity of grain-boundary diffusion (in a lesser degree of volume one) provides accelerated formation of the segregations of atoms of chromium, molybdenum, phosphorus and manganese along their boundaries [7, 9]. The rate of solid phase reactions $M_3C \rightarrow M_7C_3 \rightarrow \rightarrow M_{23}C_6 \rightarrow M_6C$ along the boundaries of grains of α-phase significantly (2–3 times) increases at the presence of such segregations in comparison with reactions between the similar precipitates localized along the grain body.

Coarsened equiaxial or length-coarsened grains of α-phase [6] or Widmanstetten ferrite can be locally formed depending on heating conditions in the area of fusion of HAZ to weld metal undergoing welding heating in T_L–T_S temperature zone. Width of fusion area makes up around 0.1–0.2 mm and metal deformation (applicable to 200,000 h of running) can be 2–3 %. In comparison the deformation of base metal (without welding heating) under similar conditions makes up 0.5–0.7 %, respectively, that fulfills the requirements of normative documents.

The shape and dimensions of the area of incomplete recrystallization of HAZ metal with approximate width of 1.2–1.7 mm depend on welding heating and have differences in thickness of welded joints. New decay products of austenite can be presented as pearlite, sorbite, troostite or bainite in this case and differ evidently on structure of the base metal [5, 6, 10–12]. Deformation of the area of metal can make up to 3–5 % and values of weakening from 5 up to 20 % in comparison with the base metal that is close to the data of study [2]. However, no weakening can be observed [6] at the presence of new decay products of austenite such as bainite or troostite. Characteristic feature of the structure of this area is a diversity of grains (Figure 4) and increased structural and chemical inhomogeneity. The physicochemical processes are more intensive in the area of metal in comparison with other areas. Their intensity significantly depends on a type of new decay products of austenite. If new decay products are represented by pearlite the structures are characterized by the greatest processes intensity. In the case of bainite they run with the smallest one. A proof is evidently increased coagulation of $M_{23}C_6$ precipitates along the boundaries of grains of α-phase and formation from such precipitates the chains having elements of uniformity (Figure 5).

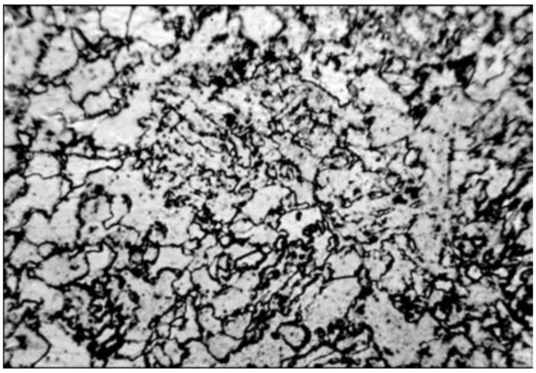

Figure 4. Microstructure (×300) of area with incomplete recrystallization of HAZ metal of welded joints on steel 12Kh1MF of direct steam pipeline (275,637 h running)

Allowable deformation of welded joint metal ($\varepsilon < < 1$ %) is characterized by a formation of substructure of grains of α-phase [3, 8] and provided by creeping and sliding of the dislocations. The effect of creeping and sliding of dislocations on the process of polygonization at different stages of its realization has the distinctive features that are related to diffusion migration of atoms of chromium, molybdenum, silicon and manganese. Stable VC precipitates uniformly distributed along the body of grains of α-phase and along their boundaries effectively stop moving dislocations. It is reasonable also that the distance between VC, longitudinal dimensions of which are close to 0.7–2.0 nm, remains in the ranges of 80–110 nm.

Stopping of dislocation mobility in the grains of α-phase also takes place with the help of friction forces (Peierls forces) through an interaction of atoms of chromium, molybdenum, vanadium, manganese and silicon with the dislocations, formation of local clus-

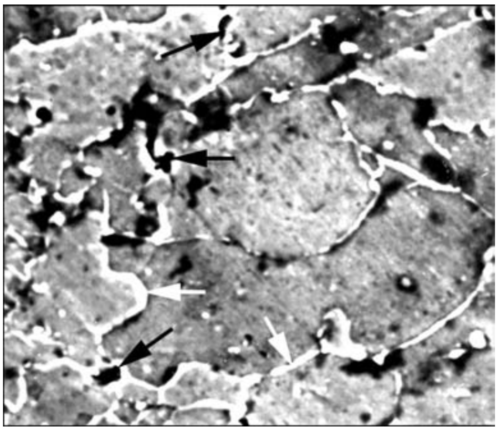

Figure 5. Microstructure (×2500) of area with incomplete recrystallization of HAZ metal with $M_{23}C_6$ precipitates along the boundaries of grains of α-phase (*light arrows*) and pores (*dark*) (the same sample as in Figure 4)

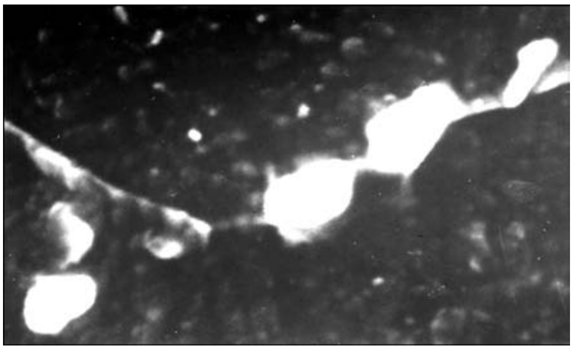

Figure 6. Microstructure (×7500) of area of HAZ with $M_{23}C_6$ precipitates after coalescence

ters of alloying elements in α-phase (of type of Guinier–Preston zones) and atmospheres of impurity atoms around the dislocations as well as barrier effect of the grains and subgrains.

It is convenient to classify the damageability of long-term operating welded joints from heat-resistant pearlitic steels by the creep mechanism as a three-stage process.

The first stage of damageability is characterized by an increase of local segregations of chromium, molybdenum, phosphorus and manganese along the boundaries of grains of α-phase, $M_3C \rightarrow M_7C_3 \rightarrow$ $\rightarrow M_{23}C_6 \rightarrow M_6C$ carbide reactions, coagulation of the precipitates of the first group including coalescence (Figure 6) as well as concentration of such precipitates along the boundaries of grains of α-phase (see Figure 5). It was determined that mainly $M_{23}C_6$ precipitates coagulate and form the chains [10]. Their amount among the carbides forming the chains makes up approximately 70 %, around 15 % of M_7C_3 precipitates and 10 % of $M_{23}C$ and ≤ 5 % of M_6C are determined, respectively.

The coalescence process of microdiscontinuities and formation of creep micropores of around 0.01–0.9 μm in size takes place during the second (incubation) stage of the damageability. Effective identification of such micropores is possible only by means of electron microscopy.

The third stage of damageability (running of less than 250,000 h) is characterized by formation of coalesced and separate micropores of 1–4 μm size as well as formation of creep micro- and macrocracks (see Figure 1). The microcracks and coalesced large micropores having branched form (Figure 7) are located in the direction of main macrocrack. Increased degree of metal deformation in the direction of macrocrack propagation provides its accelerated development. The third stage of damageability has mainly intergrain brittle character and can be well identified by using optical microscopy.

It is reasonable to identify exactly this stage of damageability in proper time and carry out repair using approved technologies [2].

There are cracks and pores in operating welded joints of steam pipelines which at their further running do not obtain propagation though their number can be critical [4, 8, 10]. Stopping in this case can be explained by the presence of a structure adjusting to the direction of cracks and pores propagation and having obviously reduced degradation. However, welded joints involving the critical level of damageability are to be repaired or replaced to avoid their sudden fracture.

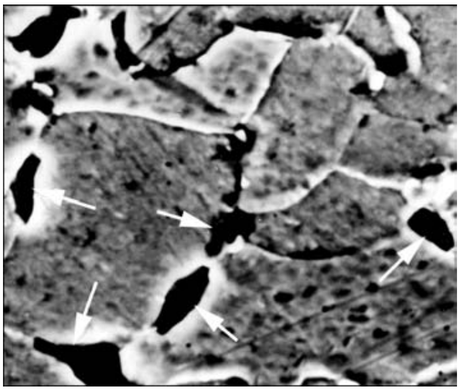

Figure 7. Microstructure (×5000) of area with incomplete recrystallization of HAZ metal of welded joint of direct steam pipeline (*arrows* — micropores along the boundaries of grains of α-phase)

CONCLUSIONS

1. It was experimentally confirmed that the damageability of welded joints by the creep mechanism significantly depends on intensity of physicochemical processes occurring in their metal during long-term operation (running of > 200,000 h).

2. The damageability of long-term operating welded joints from heat-resistant pearlitic steels by the creep mechanism should be considered as a three-stage process.

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