RECONDITIONING HEAT TREATMENT

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EFFECT OF RECONDITIONING HEAT TREATMENT ON THE STRUCTURE AND SERVICE PROPERTIES OF STEAM PIPELINE METAL

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The structure and properties of the metal of steam pipeline bends from Cr – Mo – V steels after operation and reconditioning heat treatment are considered. The expediency of such treatment is correlated with the size of the pores arising in operation of the pipeline under conditions of creep.

INTRODUCTION

At many thermal power plants of modern Russia and countries of the former USSR hundreds of steam pipelines from Cr – Mo – V steels operate after reconditioning heat treatment (RHT).

Developers of RHT are positive [1] that the structure and all properties of the metal of steam pipelines are recovered after RHT to the design values and the creep pores formed in the metal due to long-term operation are cured. It is assumed that the primary mechanism of pore curing is sintering. After RHT steam pipelines are left for further operation for from 75,000 to 130,000 h.

Today we have quite ample experience of operation of pipelines subjected to RHT. Many of them have served for about ten years after RHT but cases of damage of individual bends have been reported.

We have data that show that the effect of RHT on the structure and properties of the metal of steam pipelines can be ambiguous. Results of studies of the metal subjected to RHT under laboratory conditions have been published in [2, 3].

The aim of the present work consisted in studying the structure and properties of the metal of pipeline bends from steel 12Kh1MF after reconditioning heat treatment performed under industrial conditions.

METHODS OF STUDY

Reconditioning heat treatment was performed after long-term operation under various conditions on dismantled steam pipelines or without dismantling. The method of RHT was primarily an induction one with the use of mobile or immobile water-cooled inductors. The RHT mode was as follows: 980 – 1080°C, cooling in air, + 710 – 750°C, cooling in air. The modes of RHT were as regulated by standards.

The RHT under industrial conditions was performed on several tens of bends from steel 12Kh1MF (pipes 273 × 32 and 273 × 36 mm in size) and steel 15Kh1M1F (pipes 273 × 32 and 219 × 25 mm in size). The operating time before the RHT was 160 – 200 thousand hours at an average operating temperature of 545°C. The bends subjected to the RHT serve at thermal power plants at 530°C until present. The time of their operation by the moment of inspection was 21,000 – 26,500 h.

The structure and the microdamage of the metal of the bends before and after the RHT under industrial conditions were studied primarily by the nondestructive method of replicas [4].

RESULTS AND DISCUSSION

Prior to the RHT all the studied bends had a structure with traces of "degeneration" due to the occurrence of carbide reactions (dissolution, segregation, spheroidizing, and coagulation of carbide phases), which is typical for long-operating metal. Most of the bends were stricken with pores 1 – 5 μm in size formed in operation under conditions of creep; about half of the bends had chains of such pores.

After RHT conducted under laboratory (furnace heating) and industrial (induction heating) conditions the formed structure has a coarse-grained ferrite-bainite type. In bends

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of steel 12Kh1MF the grain size after the RHT increased from the typical No. 7 – 8 (according to GOST 5639–82) to No. 4 – 7; in bends from steel 15Kh1M1F it increased from No. 5 – 7 to No. 3 – 6.

It should be noted that when the RHT is performed under industrial conditions, the structure of the metal in different bends and even within one and the same bend is often inhomogeneous with respect to the size of actual grains and with respect to the amount, size, and structure of bainite regions. Note that at the place where the inductor has stopped the formed structure is often typical for heating in the intercritical temperature range. In addition, the structure of the metal after RHT often exhibits dark-etching “islands” of dispersed ferrite-carbide mixture. The number of “islands” decreases when the austenization temperature is increased from 950 to 1080°C. The presence of such “islands” is a sign of incomplete homogenization of austenite during heating for normalizing even at 1080°C. An electron microscope study has shown that the “islands” are represented by a mixture of dispersed carbides located in fragmented matrix.

Special attention was devoted to studying the possibility of curing creep pores by RHT. The methods of transmission electron microscopy and light metallography were used to study the metal of long-operating bends before and after the RHT. It has been shown in [2] that austenization under laboratory conditions commonly cures the pores 0.1 ± 0.05 μm in size starting with the temperature of 1020°C. The pores 1 μm in size and larger ones are preserved in the metal even in heating to 1080°C. Studies of the metal of bends subjected to RHT under industrial conditions (austenization temperature 1080°C) have confirmed that pores ≥ 1 μm in size in the metal are presented.

Identification of the pores preserved is very difficult and not unambiguous because they are commonly located inside actual grains. However, in the cases when the actual structure characterized by chemical heterogeneity of the metal preserved after RHT exhibits boundaries of “old” (prior to the RHT) grains with “old” pores on them, identification of the cured pores becomes less ambiguous, especially when the pores are joined into chains (Fig. 1). The pores preserved after RHT are primarily of a polyhedral shape, which is a sign of their growth by the diffusion mechanism, most probably, due to inflow of vacancies. A metallographic study of laps has shown that in some cases the preserved pores are filled with products of oxidation, most probably, of iron. Curing of the pores filled with oxidation products is virtually impossible.

Thus, the capacity of pores for being cured or for growth under the conditions of austenization due to RHT depends not only on the heating temperature but also on the size of the pores. Similar data on the effect of the size of particles of second phase on their capacity for growth or dissolution are described in [5].

The mechanical properties of the metal of bends determined in short-term tests meet the standard requirements after RHT performed under both laboratory and industrial conditions.

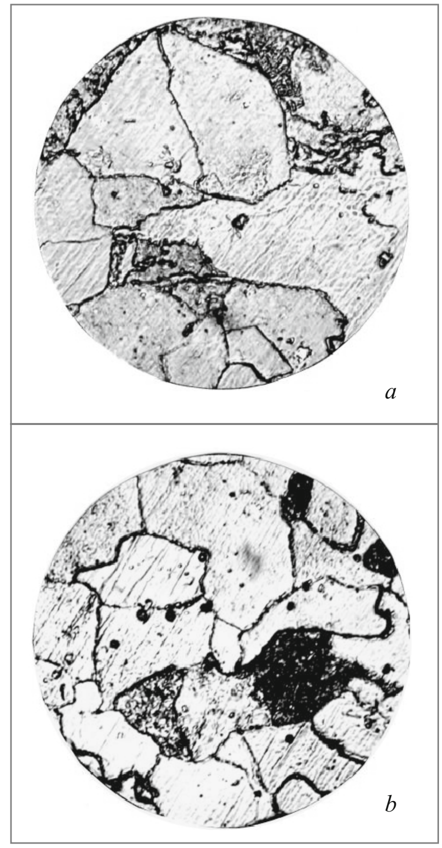

Fig. 1. Microstructure of the metal of steam pipe bends 273 × 32 μm in size with pores preserved after RHT (× 500): *a*) isolated pore, steel 15Kh1M1F; *b*) chain of pores, steel 12Kh1MF.

We tested the steels for the long-term strength after RHT performed under laboratory conditions. The earlier data of [2, 3] were supplemented by the results of new tests. All the results were generalized in the form of a function of the temperature-and-time parameter of Larsen – Miller $P_{\text{L-M}}$ (Fig. 2). Analysis of the results of the tests for long-term strength shows the following.

(1) The values of σ_{lts} obtained in the tests for long-term strength after RHT are scattered within a wide band exceeding substantially both the upper and the lower boundaries of the standardized scattering.

(2) If the RHT is applied to metal without microdamage, the long-term strength meets or exceeds the standardized value.

(3) If the metal before the RHT has a quite high level of microdamage (up to chains of pores), the long-term strength after the RHT is often below the standardized value (Fig. 2*a*).

Such scattering of the values of σ_{lts} is explainable both by difference in the level of microdamage of the metal prior to the RHT and by inhomogeneity of the structure after the RHT.

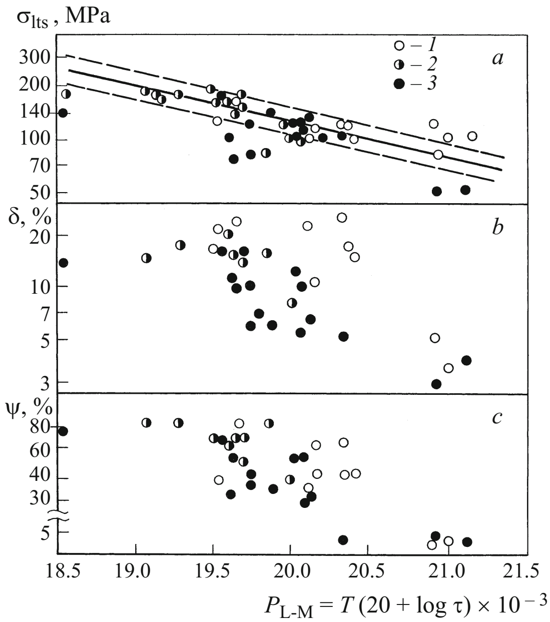

Fig. 2. Parametric dependence ($P_{L\text{-}M}$ is the Larsen – Miller parameter) of the long-term strength (*a*) and long-term plasticity (*b*, *c*) of the metal of bends subjected to RHT after long-term operation (the solid line reflects the standardized values of the long-term strength and the dashed lines mark the permissible amplitude of its scattering): *1*) undamaged bends (empty circles); *2*) bends with single pores (half-filled circles); *3*) bends with pore chains (filled circles).

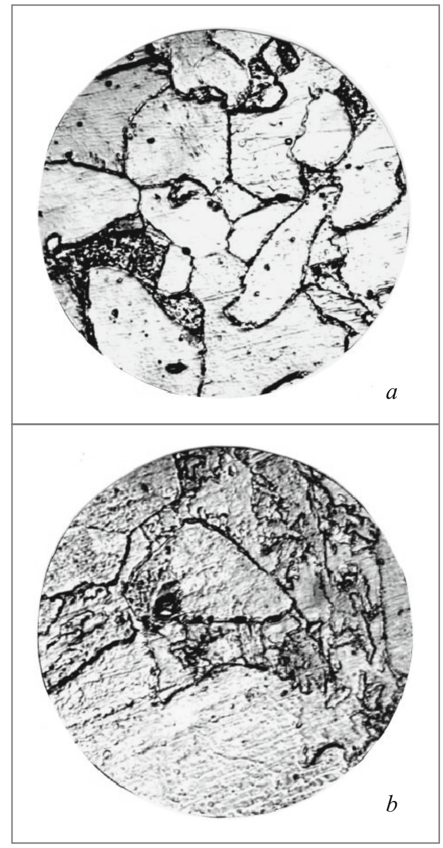

Fig. 3. Microstructure of the metal of bends of steam pipes 273 × 32 μm in size with pores formed in operation after RHT (× 500): *a*) isolated pore, steel 12Kh1MF; *b*) pore chain, steel 15Kh1M1F.

(4) The long-term plasticity after the RHT is usually lower than in the state as delivered, especially if the RHT has been applied to a metal with high level of microdamage. In the latter case the long-term plasticity may fall to impermissibly low values (δ to 3% and Ψ to 5%, Fig. 2*b* and *c*). Decline of the long-term plasticity after RHT can be caused both by coarsening of the grains and by the presence of uncured creep pores in the metal.

Results of determination of the effect of creep pores on long-term strength and plasticity of metal are presented in [6]. It is shown that growth in the level of microdamage of the metal is accompanied by substantial lowering of its operating properties determined in long-term tests.

The reliability of operation of bends fabricated from metal with low and nonuniform operating properties due to the presence of microdamage casts much doubt. The results of studies of several tens of bends of steam pipelines subjected to RHT and then put in service for 21,000 – 26,500 h at 530°C confirm this concern.

Microdamage of different level has been detected on the external surface of most bends operating after RHT even after a short time of service at quite low temperatures (isolated pores have been found in 60% of the studied bends (Fig. 3*a*); pore chains have been found in 30% of the bends (Fig. 3*b*)). In the metal of bends operating after industrial heat treatment (the state as delivered) such early development of microdamage in operation has not been determined.

It seems that it is very important to compare statistical dependences of the kinetics of development of microdamage in operation of bends after industrial heat treatment (initial state) and of bends subjected to RHT.

As applied to initial bends such data can be found in [7 – 9]. It is quite problematic to obtain similar dependences for bends subjected to RHT primarily due to the absence of data on the level of microdamage of the metal of such bends after operation and due to the absence of an appropriate volume of data of long-term strength tests.

We have performed preliminary evaluation of equivalent stresses at the moment of formation of single pore chains in bends from steels 12Kh1MF and 15Kh1M1F subjected to RHT and then put to operation. We used an assumption that the service properties of the metal after RHT are equal to the properties of the metal in the state as delivered with ferrite-bainite structure. The other data required for the computation (the values of the out-of-roundness and of the wall thickness of the bends, the service time, the operating parameters) were obtained by control of the bends.

It can be seen from Fig. 4 that the time of service before the beginning of formation of microdamage in bends from both steels (12Kh1MF and 15Kh1M1F) after RHT is several

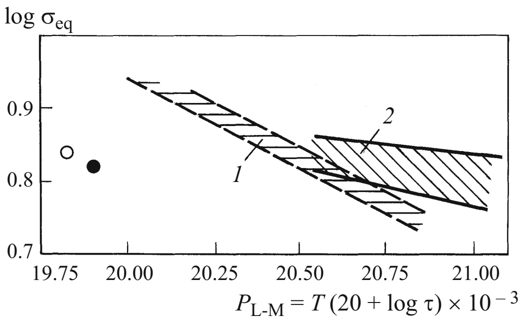

Fig. 4. Parametric dependence ($P_{L\text{-}M}$ is the Larsen – Miller parameter) of equivalent stresses at the moment of formation of microdamage of different levels: *1*, *2*) regions of development of microdamage from single pores to multiple pore chains in steels 12Kh1MF and 15Kh1M1F respectively; ○) steel 12Kh1MF after RHT and 21,000 h of operation; ●) steel 15Kh1M1F after RHT and 26,500 h of operation.

times lower than after industrial heat treatment. This allows us to expect that RHT can produce a negative effect on the operating reliability of bends of steal pipelines produced from Cr – Mo – V steels. In addition, the data obtained show that it is expedient to amend the schedule of control of bends subjected to RHT.

CONCLUSIONS

1. Standard RHT of bends of steam pipelines produced from Cr – Mo – V steels does not cure the operation-induced creep pores with a size of 1 – 5 μm.

2. Preservation of creep pores in the metal after RHT causes substantial decrease in the long-term strength, plasticity, and, especially, in the time to the start of formation of microdamage. For this reason the schedule of control of the bends subjected to RHT should be revised.

3. It is not expedient to perform RHT of steam pipeline bends the metal of which has accumulated damage in the form of pores 1 – 5 μm in size. This especially concerns the presence of chains of such pores.

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