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Dynamics of Properties and Structure Changes of Pearlite Steel during Long-lived Operation

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A decision to continue to operate power-generating plants, when the initial resource of equipment working time is ended, and its further operation without considerable expenditures on repair and diagnostic of a metal state is possible only with the help of long-term research of metal of power-generating plants. Only a complex of research techniques can estimate a real state of a construction. The article deals with the analysis of mechanical characteristics, residual strains, structure of a steel, change dynamics (time history). The results of experiments and inspection a state of a steam line steel allow to forecast further material behaviour and to make conclusions about possibility of further operation of the equipment.
Keywords: pearlite steels, mechanical properties, change of microstructure, long-lived operation.

1. INTRODUCTION

In-service time of components and units of power-generating plants, which are exposed to a high temperature and stress, is very long and lasts several tens years. In-service time is defined by plants designers. Hereinafter state of this plants systems and equipment is permanently or periodically checked up. However a moment occurs, when the design operation resource (service life) ends. After that it is necessary to define if the further operation is possible, and, if it is allowed to operate, what new operation resource has to be defined [1].

One of the most major groups of potentially dangerous equipment is equipment of thermal power stations. Damages and breakage of this equipment can be dangerous to people health and harmful to economy. Therefore a reliable operation of this systems becomes so important. The equipment of the Lithuanian thermal power stations has been already operated for many years, the inventory is obsolescent, its metal exposed to long-time effects. The initially defined working time of this equipment is up to 100 thousand hours. Therefore to guarantee reliable operation of different systems of thermal power stations it is very important to estimate a technical status of equipment and define what possible service life of a steam line can be.

The reliable operation of equipment of thermal power stations depends on reliable and without emergency operation of pipelines. The thermo-mechanical loads effect upon the metal of a power-generating plants (pipelines, drums of boiler, tubes of boiler etc.), when it is used for a long time. The temperature of an examined steam line is 545 °C. The steam pressure reaches 14 MPa.

Initially prior to the beginning of operation the structure of steel consists of ferrite, pearlite and carbides. During long-time of high temperature operation the structure of steel changes.

Prior to the beginning of operation, temperature normalized and hardened tubes from steel 12Ch1MF, residual austenite varies and the carbides from supersaturated solid solution of ferrite are derivated. The simultaneously alloying elements are arranged between ferrite and carbides [2, 3].

During long-time of high temperature operation the diffusion of alloying elements occurs and this effects to change of ferrite and pearlite ratio in structure. The ferrite is hardened because of dissolved molybdenum, chrome and vanadium in it. In grains of ferrite the fine-grained carbides are formed, which diminish a plastic deformation, as they disturb mobility of dislocations. The coagulation of carbides courses dispersion of carbides, the small carbides disappear and big ones grow. When an amount of hindrances decreases the velocity of driving dislocations increases again. It explains a change of mechanical characteristics. The ferrite matrix alloying elements during operation leaves it and transforms to a carbide phase. Thus solid solution and carbides phases changes, its quantity and composition [2 – 5].

At the same time changes of composite phases of pearlite structure also occur. The process starts by transformation of cementite plates. The small grains of a carbide are joined in major and thus a carbide inclusion under the boundaries of grains occurs. The grain boundaries are dilated, the carbides become spherical. This is the precondition of increasing of steel creeping [6 – 19].

During operation effected by 545 °C temperature and 14 MPa pressure the processes of creep constantly develop in steels. Because of coagulation and grow of a secondary phase the matrix loses alloying elements, a strengthening influence of carbides qualitatively changes.

In this work the periodic research was done on control leases of a steam line.

2. TECHNIQUE OF RESEARCH

The microsections of metal were made of different zones of control leases of steam lines [5, 6]. The

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microstructure of steel 12Ch1MF (Table 1) of a steam line elements was examined and mechanical tests were made after particular operation time: 1) on an initial state (before operation), 2) after 29572 operation hours, 3) after 70227 operation hours, 4) after 94992 operation hours.

Table 1. Chemical composition of not operated steel, %

C	Mn	Si	S	P	Cr	Mo	V
0.09	0.5	0.32	0.027	0.028	0.6	0.17	0.27

The tests of mechanical properties were done at room temperature of 20 °C and working temperature of 545 °C. The results of tests were treated with the help of the program “Statistica”. Each experiment point corresponds to a average value of three experimental measurements. The regression line characterizes a average value of mechanical characteristics of a steel of a steam line.

3. RESULTS OF METALLOGRAPHY EXAMINATION OF A STEAM LINE METAL

After first 15 – 20 thousand hours operation of pipelines made of steel 12Ch1MF at the temperature of 545 ˚C and pressure 14 MPa the considerable changes of structures occur. The changes of ferrite chemical composition, coagulation of carbide in ferrite, and also increase of sizes of carbides along the grain boundaries was observed. After 50 thousand hours of operation there are 48 % molybdenum and 20 % chrome in a composition of carbides (Table 2).

The microstructure of metal of a steam line is presented on photographs (Fig. 1, 2, 3 and 4). They show that microstructure of specimens consists of ferrite, pearlite and non-metallic inclusions [1].

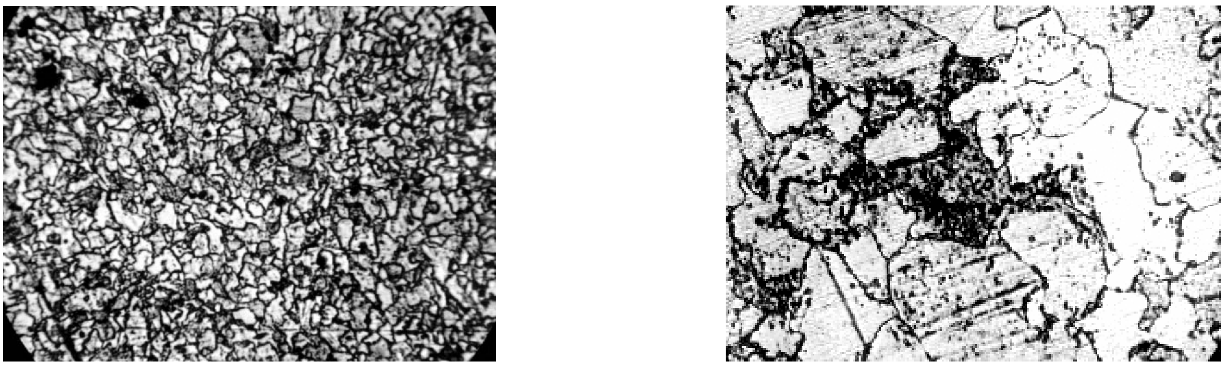
The microstructure of not operated steel (Fig. 1 a, b) consists of pearlite (black phase), ferrite (white phase) and non-metallic inclusions. According to the standard 14-3-460 scale the microstructure of steel corresponds to numbers 3 – 4.

Table 2. Changes of chemical composition of carbide phases

Time,hours	0	29572	70229	94942
The quantity of Cr in Cr carbides, %	19	19.6	20.9	28.9
The quantity of Mo in Mo carbides, %	45.6	46.7	48.8	48.9
The quantity of V in V carbides, %	67	68	68.4	69
The quantity of carbide phases, %	1.2	4.283	12.251	19.876

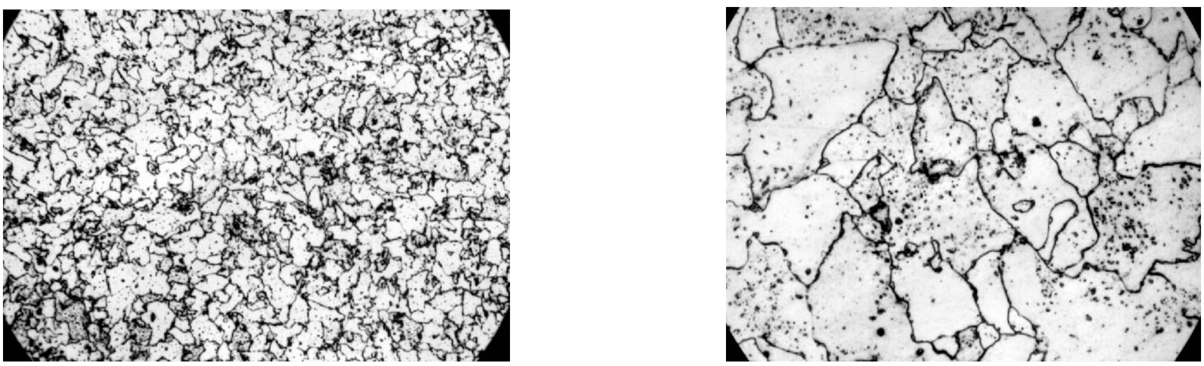
The photographs (Fig. 2 a, b) show the microstructure of 29572 hours operated steel. The microstructure of steel corresponds to number 6 of a scale of standards according 14-3-460. Changes of the microstructure are visible on the photographs. The microstructure consists of ferrite, pearlite and non-metallic inclusions. On the boundaries of ferrite grains line-ups of carbides are visible (Fig. 2 b).

On the photographs (Fig. 3 a, b) the microstructure of 70229 hours operated steel are presented. The microstructure of steel corresponds to number 6 – 7 of a scale of standards according 14-3-460. The microstructure consists of ferrite, pearlite and non-metallic inclusions. In comparison with a microstructure of 29572 hours of operated steel, an amount of carbides and their coagulation in ferrite increases (Fig. 3 b).



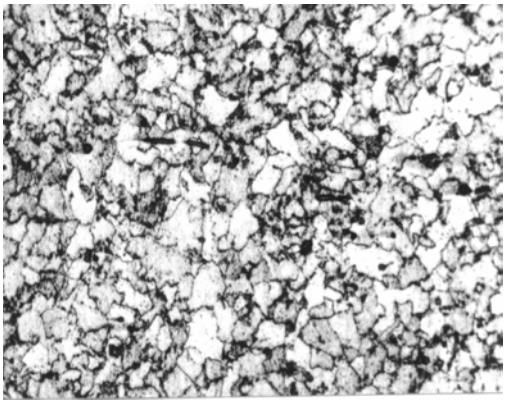
a (×100) b (×500)

Fig. 1. Microstructure of not operated steel 12Ch1MF of a steam line

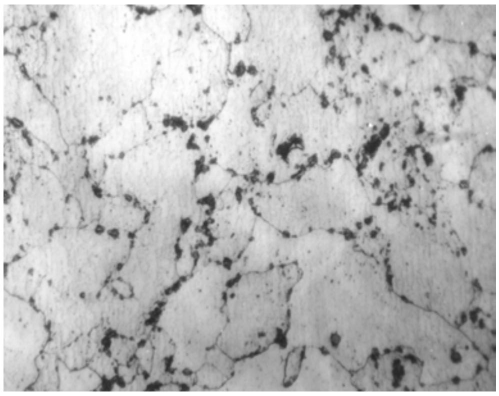


a (×100) b (×500)

Fig. 2. Microstructure of steel 12Ch1MF of a steam line after 29572 hours of operation

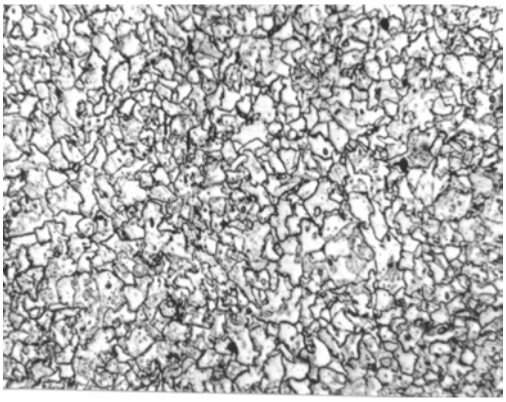


a (×100)

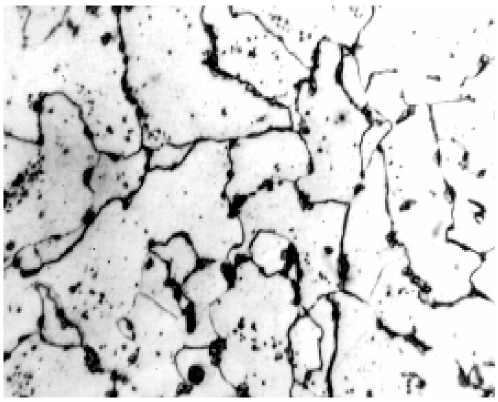


b (×500)

Fig. 3. Microstructure of steel 12Ch1MF of a steam line after 70229 hours of operation



a (×100)



b (×500)

Fig. 4. Microstructure of steel 12Ch1MF of a steam line after 94942 hours of operation

On the photographs (Fig. 4 a, b) the microstructure of 94942 hours operated steel are presented. The microstructure of steel corresponds to number 7 of a scale of standards according 14-3-460. The microstructure consists of ferrite, carbides and small amount of pearlite. In the body of grains of ferrite it is possible to see the small particles of carbides, but the major part of carbides are between the boundaries of grains (Fig. 4 b).

Observed changes of the steel structure determine changes of mechanical and physical characteristics of the metal of pipelines.

4. RESULTS OF MECHANICAL CHARACTERISTICS RESEARCH

The results of mechanical characteristics provided at a room temperature and at working temperature are presented on (Fig. 5 – Fig. 9). Major changes of values of ultimate tensile strength and yield strength established at a room temperature were not determined. At increase of ageing time (at working temperature) the strength properties decrease. The most intensive processes take place during the first 30000 – 50000 working hours, later they are stabilized. The yield strength and ultimate tensile strength of steel of a steam line operated 100000 hours decrease. At the same time, testing at working temperature, the yield strength in the beginning of operation decreases, but when duration of operation reaches 30000 hours it begins to grow. Comparing changes of ultimate tensile strength and yield strength after 110000 hours of operation, it is possible to make a conclusion that there are no major changes of strength properties. Plastic properties during this operation period have increased. At the same time impact strength *KCV* and hardness almost did not change (Table 3). A level value of short-lived strength properties of a steel during 110000 hours of operation corresponds to calculated properties and technical requirements. Established at a working temperature ultimate tensile strength and yield strength were 250 and 150 MPa.

Table 3. Dependence of mechanical characteristics of steel and (at 20 ˚C) strain of a steam line units on operation time

Time, hours	0	29572	70229	94942
Hardness, HB	143 – 168	130 – 175	135 – 146	145 – 160
Strain, %	0	0.01 – 0.21	0.08 – 0.33	0.18 – 0.48

The research of early-happened failures of steam lines, made possible to determine, that the short-lived mechanical characteristics of metal of these steam lines conform to the technical requirements. It lead to conclusion, that at evaluation of operation reliability of separate units of a steam line it is impossible to use only values of short-lived mechanical characteristics of a steel. The short-lived mechanical characteristics of a steel can be only used as additional information characterizing the quality of metal of a steam line unit.

As one of indexes of an operation reliability of a steam line metal can be proposed a ratio of ultimate tensile strength at working temperature to ultimate tensile strength at a room temperature $\sigma_B^t / \sigma_B^{20}$. Analysis of reasons of the occurred failures of pipe steam lines, made possible to determine, that the critical value $\sigma_B^t / \sigma_B^{20}$ ratio of long time operated steel 12Ch1MF is equal $\sigma_B^t / \sigma_B^{20} \geq 0.5$.

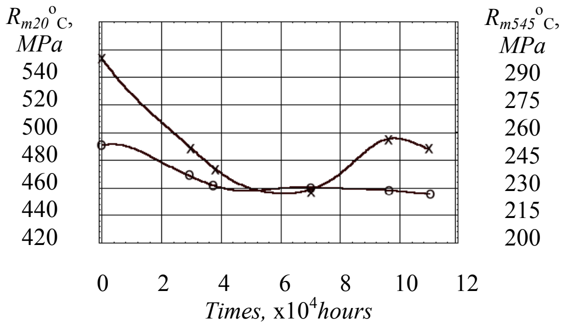


Fig. 5. Dependence of ultimate tensile strength on time of operation: o – the research was done at the 20 ˚C temperature, × – the researches was done at the 545 ˚C temperature

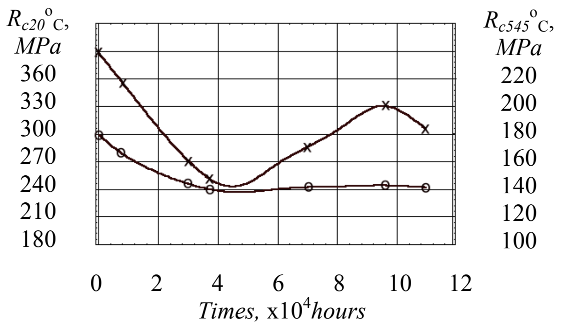


Fig. 6. Dependence of yield strength on time of operation: o – the research was done at the 20 ˚C temperature, × – the researches was done at the 545 ˚C temperature

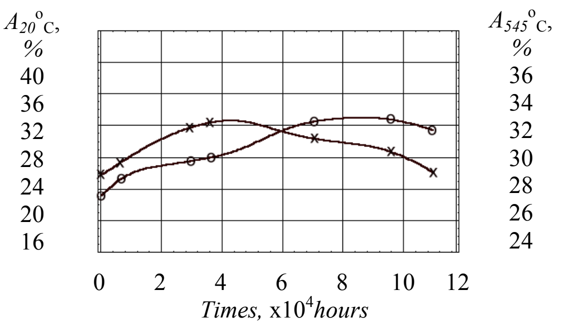


Fig. 7. Dependence of elongation on time of operation: o – the research was done at the 20 ˚C temperature, × – the researches was done at the 545 ˚C temperature

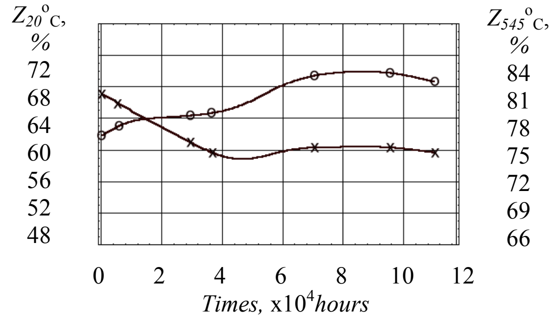


Fig. 8. Dependence of area reduction n time of operation: o – the research was done at the 20˚C temperature, × – the researches was done at the 545˚C temperature

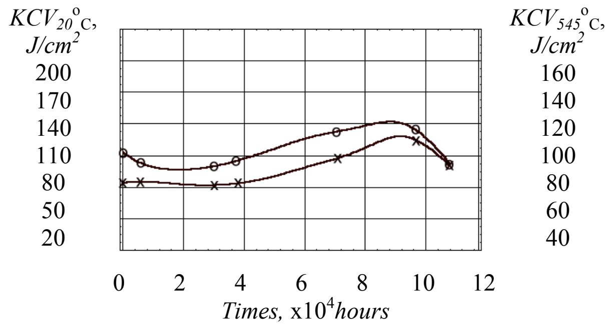


Fig. 9. Dependence of impact strength on time of operation: o – the research was done at the 20˚C temperature, × – the researches was done at the 545˚C temperature

5. CONCLUSIONS

1. Continuous time high temperature operation leads to changes of steel structure. There is a change of constituents of ferrite and pearlite of a steel. The grains of ferrite grow and their coagulation occurs, pearlite is diminished.
2. It was determined, that the alloying elements (chrome, molybdenum and vanadium) during a high temperature long-term operation from ferrite solid solution to transform into a carbide phases. During a long-term operation at high temperature the amount of carbides increases and coagulation of carbides occurs, therefore freedom of dislocations mobility increases, and it increases a creep of material and defines change of other mechanical characteristics.
3. On evaluating a further opportunity of operation of a steam line the basic limiting parameter of the long time operated heat-resistant steels is dispersity of carbides.
4. All mentioned properties have non-linear changes. Long-term operation at working temperature of 545 °C lead to change of ultimate tensile strength and yield strength, elongation and reduction of area, impact strength and hardness.
5. After 110000 hours of operation the short-lived mechanical characteristics of a metal of steam lines conform to the requirements of the technical conditions.

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