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THE INFLUENCE OF REPAIR WELDED JOINT ON THE LIFE OF STEAM PIPELINE MADE OF Cr-Mo STEEL SERVICED BEYOND THE CALCULATED WORKING TIME

WPŁYW NAPRAWCZEGO ZŁĄCZA SPAWANEGO NA TRWAŁOŚĆ RUROCIĄGU PARY ZE STALI Cr-Mo EKSPLOATOWANEGO POWYŻEJ OBLICZENIOWEGO CZASU PRACY

The aim of the paper was to examine the influence of repair welded joints on the service life of steam pipelines for over 220 000 hours of service in creep conditions. The research included the study of the microstructure using scanning microscopy, the tests on mechanical properties at room and elevated temperature, determining the nil ductility transition temperature, and short-time creep tests to determine the residual life of the material. The tests allowed determining the time of further safe operation of elements of the steam pipeline with a repair welded joint, with reference to the base material, and the welded joint after service. The assessment of residual life and disposable residual life, and at the same time determining the possible time of further safe operation, has an essential meaning in the case of elements serviced considerably beyond the calculated working time.

Keywords: creeping, material diagnostics, welded joints after service, Cr-Mo steel, residual life

Celem pracy było zbadanie wpływu naprawczych złączy spawanych na trwałość eksploatacyjną rurociągów pary przez ponad 220 000 godzin eksploatacji warunkach pełzania. Wykonano badania mikrostruktury z wykorzystaniem mikroskopii skaningowej, badania właściwości mechanicznych w temperaturze pokojowej i podwyższonej, wyznaczono temperaturę przejścia w stan kruchy, przeprowadzono skrócone próby pełzania celem wyznaczenia trwałości resztkowej materiału. Przeprowadzone badania pozwoliły na wyznaczenie czasu dalszej bezpiecznej eksploatacji elementów rurociągu pary z wykonanym naprawczym złączem spawanym w odniesieniu do materiału rodzimego i złącza spawanego po eksploatacji. Ocena trwałości resztkowej i resztkowej trwałości rozporządzalnej, a tym samym oszacowanie lub wyznaczenie możliwego czasu dalszej bezpiecznej eksploatacji ma zasadnicze znaczenie w przypadku eksploatacji elementów znacznie poza obliczeniowy czas pracy.

1. Introduction

The 200-500 MW power units designed in the 1970s exceeded the calculated working time of 100 000 hours. This time resulted from the parameters applied for the calculations, connected with the creep-rupture strength. The possibility of further service beyond the calculated working time, frequently above 200 000 hours, and lately even above 300 000 hours, results from a range of safety factors used in the design phase [1-5]. Moreover, other factors that also have an influence on it are as follows: the mean creep-rupture strength, whose actual value cannot be higher than the mean value assumed for calculations, the actual thickness of wall bigger than the calculated thickness, and actual parameters of work (temperature, pressure), most frequently lower than the assumed calculated ones. The above-mentioned factors in practice or normal service, with fairly performed routine diagnostics and economically grounded modernization works, allow extending the working time considerably beyond the calculated time [6-9]. It should be mentioned that in the case of extension of the service time of critical elements of a boiler above 200 000 hours, it is necessary to determine the residual creep strength [1,10]. In particular, it concerns the steels and their welded joints of the main steam pipelines. The knowledge of the actual creep strength of the material and the welded joint after service is crucial in determining the further safe operation time of the pipeline for the defined parameters of further work. A significant issue in the assessment of the condition of steam pipelines is also the knowledge of the creep strength of the repair welded joints, understood as rejoining of the materials serviced earlier in creep conditions [11,12].

In the assessment of construction elements working in creep conditions, such as steam pipelines, it is essential to evaluate the condition of their base material, the heat-affected zone, and the weld seams of the serviced welded joints. It is most often performed on the basis of material non-destructive and destructive tests, for which a set of research methods is chosen, depending on the element availability and the ability of sampling the material for destructive tests [1]. After comparing with the available characteristics of materials after

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service, the condition of the material is assessed, and on the basis of this assessment, the safe operation time is estimated for the parameters of further service. However, in the case of elements working above 200 000 hours, not only estimating the residual life is required. It is also necessary to determine residual life on the basis of the destructive tests on a representative tests piece sampled for the research (Fig. 1) [1].

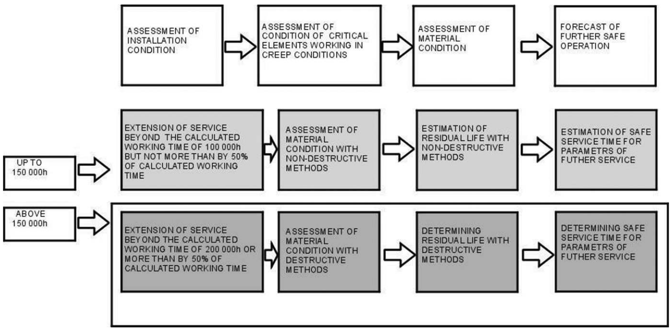

Fig. 1. Assessment of the material condition and the forecast of service life of elements of pressure parts in steam boilers working in creep conditions, depending on the time of their service [1, 11]

The subject of the present study is the assessment of service life of circumferential welded joints in the steam pipeline made of low-allow steel (Cr-Mo) after long-term service in creep conditions above the calculated working time. The results of the performed tests of microstructure, mechanical properties, and creep tests allowed the authors to propose a way of proceeding in the assessment of welded joints after long-term service and repair. However, it requires having a database in the form of materials characteristics including strength properties, plastic properties, microstructural changes, and above all, the characteristics of creep strength of the welded joints materials after service in creep conditions, of various degrees of degradation. All of the above is needed to evaluate the condition of the material of construction elements on the basis of the non-destructive and destructive tests [13].

2. Material and methodology of research

The examined material was a section of a steam pipeline made of 10CrMo9-10 (10H2M) steel, measuring φ 508×20 mm, with a homogeneous circumferential welded joint, after 227 000 hours of service, with the pressure of 3 MPa, at the temperature of 540°C. Chemical composition of 10CrMo9-10 steel is presented in Table 1. Additionally, on the received section in the industrial conditions, a "repair" welded joint was made, aiming to simulate the repairs of steam pipelines performed through welding.

TABLE 1

Chemical composition of 10CrMo9-10 steel, % mass.

C	Mn	Si	P	S	Cu	Cr	Ni	Mo
0.10	0.48	0.27	0.010	0.017	0.084	2.27	0.09	0.99

The tests of mechanical properties included the static test of tension at room and elevated temperature using the Zwick testing machine of max load of 200 kN, the measurement of hardness with Vickers method using the Future – Tech FM – 7 hardness tester with the indenter load of 10 kG, and the impact strength test on standard test pieces with the V-notch. Microstructural tests were carried out with the use of scanning electron microscope, Inspect F (SEM), on metallographic specimens etched with nital. Creep tests at the temperature higher than the temperature of work and the stress similar to the operational one were performed one-sample machines by Instron, with the accuracy of temperature during the test duration ±1°C.

Short-time creep tests were conducted at constant stress of the test, corresponding to the stress during the service $\sigma_b = \sigma_r$ = const, and at constant temperature of testing T_b for each of the tests, but of different values from 620°C to 700°C with gradation by 20°C. The results of short-time creep tests of the base material, the joint after service, and the repair joint were performed at constant level of stress amounting to σ_b = 55 MPa. Residual life is determined by extrapolation of the obtained straight line towards lower temperature corresponding to the operational Te.

3. Results of research

3.1. Microstructural tests

Figure 2 presents en example of the microstructure of the base material after service. After long-term service, the base material was characterized by a ferritic – bainitic microstructure. The dominant phase in the microstructure of the investigated steel was quasipolygonal ferite with very fine numerous precipitates evenly distributed inside the grains. In bainitic areas, a considerable number of carbides of diverse size was observed, with a visible progressive coagulation process. On the boundaries of ferrite grains, there were precipitates of diverse size observed, forming "a continuous grid of precipitates" in some areas.

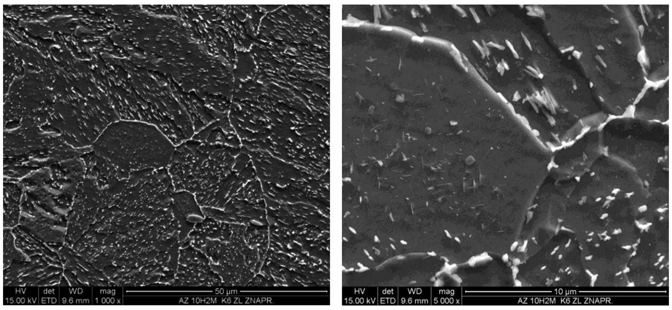

Fig. 2. Microstructure of base material after service

In the heat-affected zone (Fig. 3) of the joints after service, a microstructure consisting of ferrite with numerous precipitates of diverse size and shape close to spherical were observed, arranged inside the grains and on the grain boundaries. The precipitates located on the grain boundaries, similarly as in the base material (Fig. 2), in some areas, formed the so-called "continuous grid of precipitates". Highly advanced process of degradation of this area of joint is mostly connected with the influence of welding process and heat treatment after welding on the changes in microstructure, and depends on the service to a smaller extent.

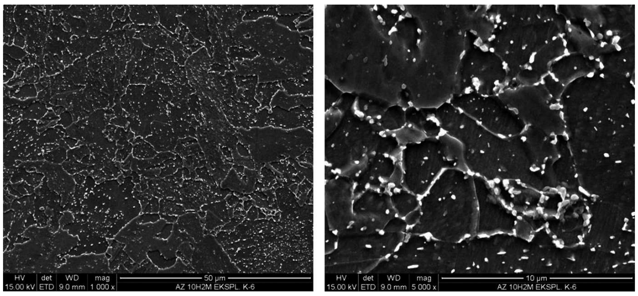

Fig. 3. Microstructure of heat-affected zone of welded joint after service

Advanced degradation of this area compared with the base material, among other things through the processes of polygonization of the matrix, and the precipitation and coagulation of M_6C carbides [14] can contribute to the formation of a joint of the so-called IV-type cracks in this area.

The microstructure of heat-affected zone (Fig. 4) of the repair joint was a ferritic – bainitic microstructure with numerous carbides of dominant lamellar shape.

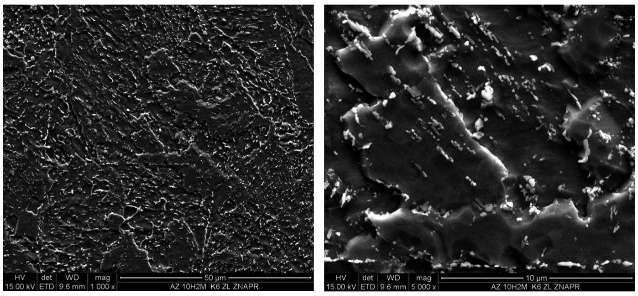

Fig. 4. Microstructure of heat-affected zone of welded joint after repair

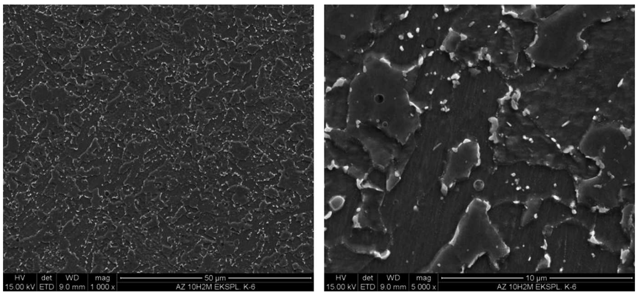

Fig. 5. Microstrucure of weld seam of welded joint after service

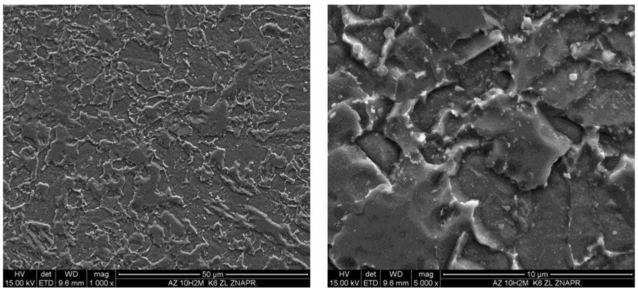

Fig. 6. Microstrucure of weld seam of welded joint after repair

The observed microstructures in the welded joint after long-term service (Fig. 5) and after repair (Fig. 6) were similar. In the bainitic microstructure of the weld seam after service (Fig. 5), however, more advanced precipitation processes were visible.

3.2. Mechanical properties

Mechanical properties of the base material, the welded joint after service, and the repair joint are presented in Table 2.

TABLE 2

Mechanical properties of examined elements of reheater steam pipeline *(minimum requirements for the examined steel according to [15] given in the brackets)*

Examined area	**Temperature of testing, °C**	**Mechanical properties**		
		YP, MPa	**TS, MPa**	**El., %**
Base material	20	285 (*min. 265*)	449 (*min. 440*)	38 (*min. 20*)
	500	217 (*min. 186*)	311	26
	550	186	287	27
Welded joint after service	20	275	453	21
	500	221	321	22
	550	191	278	20
Repair joint	20	289	500	20
	500	231	358	19
	550	218	304	20

Performed tests have shown that the strength properties (YS, TS) and plastic properties (El.) determined at room and elevated temperature of the above materials are higher than the minimum requirements set by the standard [15] for this grade of steel. The repair joint in comparison with other examined materials was characterized by the highest strength properties, with its plastic properties similar to those of a joint after service.

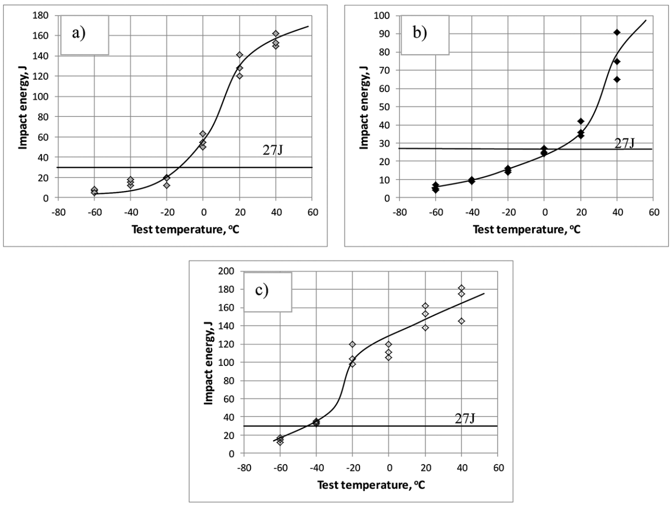

Fig. 7. Determined nil ductility transition temperature for: a) base material, b) material of weld seam after service, c) material of repair weld seam

The value of impact strength and the nil ductility transition temperature depends on the condition of the microstructure and the corresponding degree of exhaustion of the examined material. Together with the growth of degree of degradation, there is a shift of nil ductility transition temperature towards higher temperature. The nil ductility transition temperature determined for the investigated materials, that is the base material, welded joint, and repair joint, amounted respectively to: -15°C, +10°C, and -40°C (Fig. 7). The low nil ductility transition temperature of the base material indicates a slight degree of degradation of the steel microstructure.

Higher impact strength and lower transition temperature of the repair joint in comparison with the joint after service probably results from the less advanced precipitation processes (Fig. 5, 6). Positive temperature of transition of the weld seam material of the welded joint after service puts an absolute obligation of fulfilling the required conditions when starting up and shutting down the boiler.

The measurement of hardness of elements of welded joint after service did not show any rapid changes at the transition through particular joint zones, unlike the elements of repair joint (Fig. 8). Hardness in particular zones of the joint after service differs by the maximum of around 55 units and does not exceed 220 HV10. Whereas hardness of the repair welded joint does not exceed the acceptable value of 350 HV10 and ranges from around 150 HV10 in the ares of base material to around 240 HV10 in the weld seam.

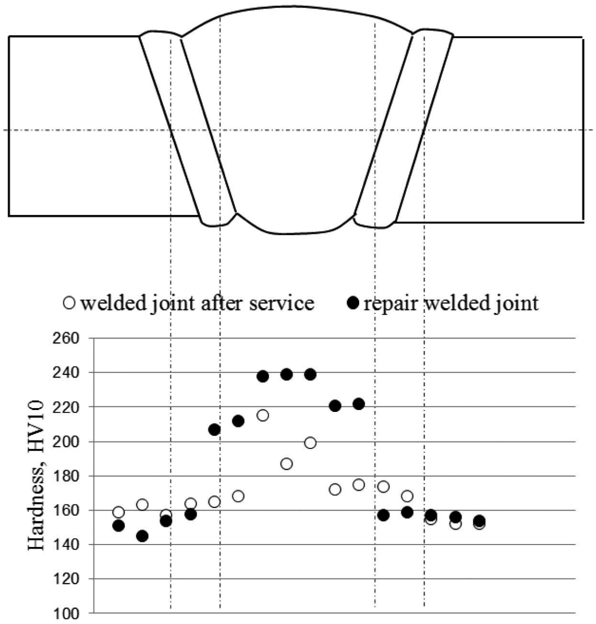

Fig. 8. Distribution of hardness on cross section of welded joint after service and repair welded joint

A lighter course of changes in hardness on the cross section of the joint after service compared with the repair joint probably results from the changes running in the microstructure of this area during long-term service.

3.3. Creep tests

In order to shorten the time of the performed creep tests and the assessment of residual life, short-time creep tests were applied, lasting from a several dozen hours to a dozen thousand hours. It allows obtaining the characteristics of creep-rupture strength of the examined materials after service beyond the calculated working time. It enables good estimation of residual life of the investigated material, which has been verified inter alia in [1, 2, 16].

The results of short-time creep strength of the base material, the joint after service, and the repair joint are presented in Fig. 9.

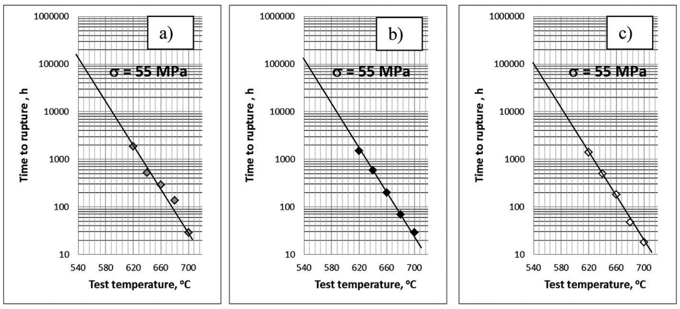

Fig. 9. Creep-rupture strength of: a) base material, b) material of weld seam after service, c) material of repair weld seam

On the basis of the results of short-time creep tests, residual life and the disposable residual life were determined for the examined condition of materials, for the assumed parameters of further service, $T_r = 540°C$ and $\sigma_r = 55$ MPa. Obtained results of tests are given in Table 3.

TABLE 3

Estimated residual life and disposable residual life

	Residual life, h	Disposable residual life, h
Base material	150 000	90 000
Joint after service	120 000	72 000
Repair joint	100 000	60 000

Disposable residual life is defined as the time from achieving the second creep period [1], thus the obtained numerical value (Table 4) is the forecasted time of further safe operation.

The base material was characterized by the bigger disposable residual life (90 000 h). Whereas the life of the repair welded joint (60 000 h) was lower than the disposable life of the joint after service (72 000 h) by 18%.

4. Summary

The research carried out on the material of reheated steam pipeline made of Cr-Mo steel and its welded joint has shown that long-term service for over 220 000 hours does not disqualify the material for further safe service. It has been proved that the modernization and repair works performed on the materials of steam pipelines after service do not have an influence on the deterioration of mechanical properties, however, they cause a decrease in creep strength. The decrease in this parameter should be considered in the design calculations when extending the time of service beyond the calculated working time.

It has also been shown that the short-time creep tests, contrary to the microstructural tests and the tests of basic mechanical properties, enable actual determining of safe operation time of elements of power engineering facilities working beyond the calculated time.

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