A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
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EXAMINATION OF COIL PIPE BUTT JOINT MADE OF 7CrMoVTiB10 – 10(T24) STEEL AFTER SERVICE

BADANIE PODCZAS REMONTU ZŁĄCZY DOCZOŁOWYCH RUR WYKONANYCH ZE STALI 7CrMoVTiB10 – 10(T24)

The paper presents the results of examination of coil pipe butt joint made of 7CrMoVTiB10-10 steel (T24). Tested joint was in service for approximately 12 000 hours at the temperature of 540°C and pressure of 5.48MPa. Tests have revealed that the structure of all regions of the homogenous welded joint are correct and without any welding imperfections. Operation of the weld contributed mainly to advantaged precipitation of carbides especially on grain boundaries – frequently in the contact area of three grains' boundaries as well as in the form of continuous network of precipitates. The measurement showed high hardness of the weld, what indicates high stability of the microstructure. It makes possible to find that post-weld heat treatment is indispensable.

Keywords: T24 steel, welded joint, microstructure

W pracy przedstawiono wyniki badań doczołowego złącza spawanego rury wężownicy ze stali 7CrMoVTiB10-10 (T24). Badane złącze eksploatowane było przez około 12 000 godzin w temperaturze 540°C przy ciśnieniu 5.48 MPa. Przeprowadzone badania wykazały prawidłową budowę we wszystkich strefach jednorodnego złącza spawanego bez niezgodności spawalniczych. Eksploatacja badanego złącza przyczyniła się przede wszystkim do uprzywilejowanego wydzielania węglików po granicach ziaren, często na styku trzech granic ziaren oraz w postaci tzw. ciągłej siatki wydzieleń. pomiar twardości wykazał wysoką twardość złącza, co wskazuje na dużą stabilność mikrostruktury. Pozwala to na stwierdzenie o konieczności stosowania zabiegów obróbki cieplnej po spawaniu.

1. Introduction

The activity toward the reduction of pollutants emission to the atmosphere, so-called greenhouse gases, trough the improvement of the efficiency of power units and reduction of fuel consumption involves the increase of steam parameters, i.e. steam pressure and temperature. The application of higher parameters of steam in power units is possible only as a result of the introduction of new materials in the power industry. The demand for the advanced heat resisting materials was the impulse towards their development. Numerous research projects resulted in the development and implementation of a new group of steel, so-called martensitic steels containing 9÷12% Cr as well as other additives and micro-additives such as molybdenum, tungsten, vanadium, niobium and boron, in the power generation industry [1, 2].

Higher parameters of superheated steam influenced also the service conditions for steel designed for components of hermetic walls. Therefore steels 16Mo3 or 13CrMo4-5 previously applied to produce such parts failed to meet those requirements. For this reason new bainitic steel grades – 7CrWVMoNb9-6 (T/P23) and 7CrMoVTiB10-10 (T/P24) have been produced. Those steels have been developed as a result of modification of chemical composition of steel 10CrMo9-10, and one of the main criteria was the elimination of post-weld heat treatment during welding of thin-walled components [3, 4].

The application of titanium as the micro-additive in steel T24 creates some problems while welding. Titanium is an element of the chemical affinity with oxygen and during welding process burns out in an out-of-controlled manner which has an adverse effect on the creep strength of a weld [5] as well as may be the reason for faster degradation of this region comparing to heat affected zone or parent metal. Therefore the assessment of the influence of working parameters on the

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microstructure and mechanical properties of a joint is an important cognitive issue in the aspect of safe operation of components in power units.
This paper presents the results of the examination of the homogenous welded joint in T24 steel after service in creep conditions.

2. Material and testing methodology

The subject of research was a homogenous joint of a steam resuperheater coil pipe of bainitic steel 7CrMoVTiB10 -10(T24) and dimensions: outside diameter 50.95mm and wall thickness 5.10mm. Chemical composition of parent metal – T24 steel is shown in Table 1.

TABLE 1
Chemical composition of T24 steel, mass fraction %

Chemical elements content, mass fraction %									
C	*Mn*	*Si*	*P*	*S*	*Cr*	*V*	*Ti*	*Mo*	*B*
0.044	0.47	0.28	0.016	0.002	2.29	0.23	0.08	1.00	0.004

The tested component was in service in 460MW CFB fluidisation boiler for approximately 12 000 hours at the temperature of 540°C and pressure of 5.48MPa. The joint was produced using method 141. Hardness measurement was performed with Vickers method using hardness testing machine Future – Tech FV700 at indenter loading of 10kG (98.07N). The microstructure was examined on the conventionally prepared and Nital etched metallographic specimen. The observation and recording of microstructures images were conducted with Axiovert 25 optical microscope (OM) and JEOL JSM 6610LV scanning electron microscope (SEM).

3. Research results and discussion

3.1. Macroscopic and microscopic examination

Macroscopic and microscopic examination was performed in accordance with PN–EN 1321 standard [6].The examination has revealed that the shape of a weld is correct and without any welding imperfections. Macrostructure of the welded joint is shown in Fig. 1.

Microstructural examination has failed to reveal microcracking as well as confirmed the correct microstructure in all regions of the homogenous welded joint. The examinations of the welded joint microstructure were performed in all regions of the welded joint (Fig. 2). Parent metal – steel T24 had a fine-grained bainitic microstructure (Fig. 2a, 2b). According to the research [7] this microstructure is the most desirable microstructure of T24 steel in the initial state (subsequent to heat treatment) in the case of production of homogenous welded joints. On grain boundaries in parent material isolated large, approximately 1μm carbides (frequently precipitated in the contact area of three grains' boundaries) have been revealed. So called continuous network of precipitates on boundaries have been observed as well. Grain size determined basing on diagram examples [8] for parent material was 9.5; which corresponds to average grain diameter of 13.1μm. In the welded joint lower bainite microstructure was found (or a mixture of lower bainite with martensite) with numerous carbides of various sizes, precipitated both on prior austenite grain bounda-

Fig. 1. Macrostructure of a welded joint, Nital etching, magnification ~6x

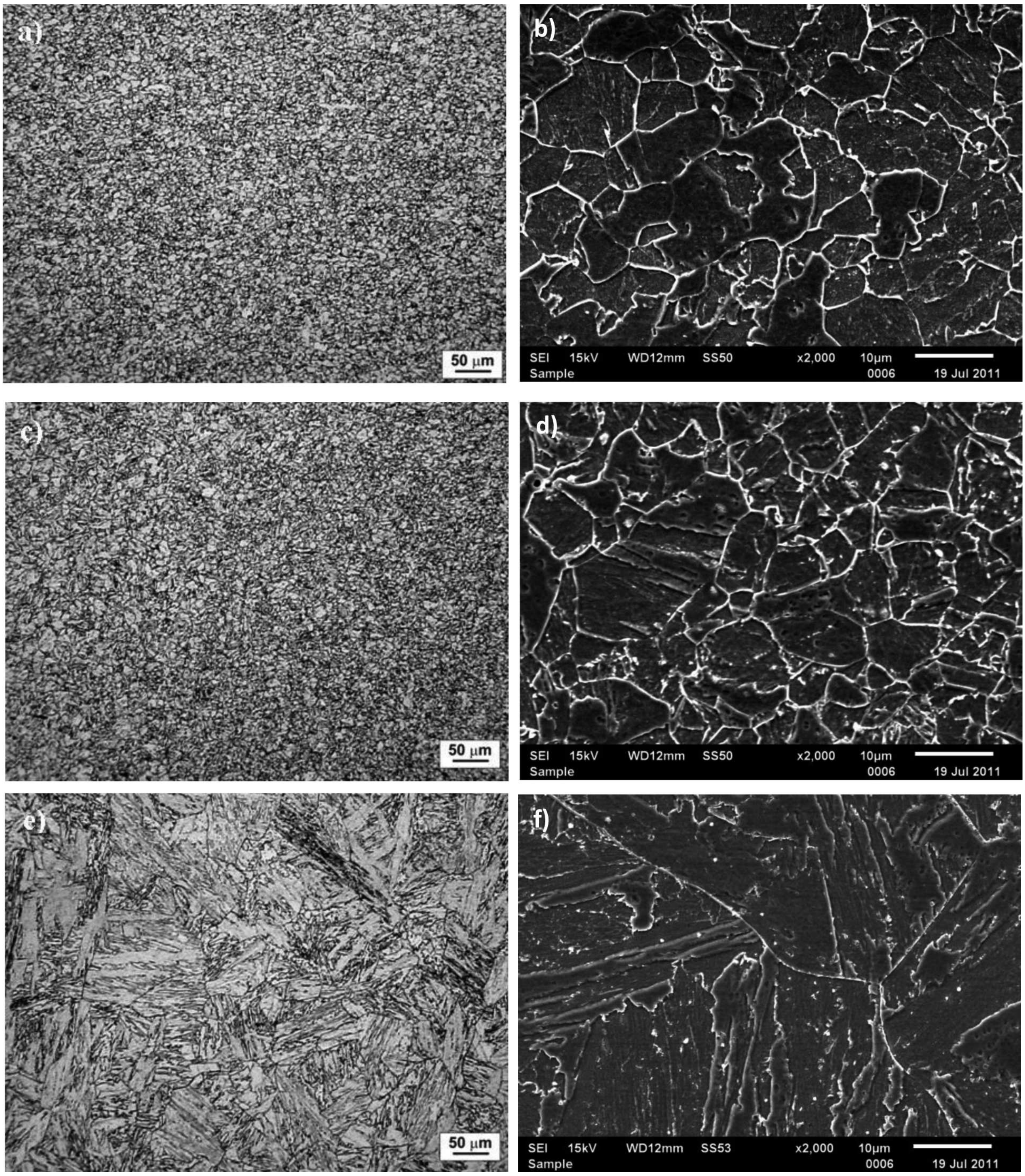

Fig. 2. Microstructure of homogenous joint in steel T24: a, b) parent metal; c, d) heat affected zone; e, f) weld, nital etching, OM, SEM

ries, bainite banding boundaries and inside the grains (Fig. 2c ÷ 2f). It should be noted that in the heat affected zone which was heated while welding to the temperature corresponding the diphase range $A_{c1} - A_{c3}$, the partial transition of bainite to austenite occurs, which results in creation of "fresh" austenite while cooling. Research [9] has revealed that decohesion of the joint takes place most often in the region heated up to the intergranular temperature $A_{c1} - A_{c3}$.

Microstructure of lower bainite (or a mixture of lower bainite and martensite) of a weld and lower bainite in the heat affected zone contribute to the creation of high internal stresses for which lack of postweld heat treatment – stress relief annealing – creates favourable conditions. This microstructure results in achieving high hardness between separate weld zones but simultaneously it causes the increase in temperature of brittle transition to the temperature above zero [7, 10]. In the joint area, like in parent metal, large isolated carbides occurred on grain boundaries as well as continuous network of precipitates was observed. The joint, compared to parent metal, was characterised by various grain sizes; according to standard scale from 10 (in normalised region) through 7/8 to 4 for a weld (the region heated up to temperature A_4) which correspond to the average grain diameters of 11; 31.2/22.1 and 88.4μm respectively. The grain size in acicular structures is of the essential importance, as fine grain not only improves opposing properties, i.e. yield point and impact resistance, reduces temperature of brittle transition but according to research [11] influences also the improvement of creep strength. Precipitation processes in discussed regions were more intense on prior austenite grain boundaries and bainite banding boundaries than inside the grains. Advantaged precipitation processes on grain boundaries and related reduction of chromium and especially molybdenum and carbon in the matrix result not only in the decrease in solid solution strengthening but also they can contribute to the improvement of phosphorus concentration in the region near the boundary. Literature data reveal that in steel T24 while creeping process there is the carbide M_6C precipitation [12] on the grain boundaries at the expense of carbides $M_{23}C_6$ which also precipitate on the grain boundaries as well as MC type precipitations are enriched with molybdenum [13]. The precipitation and growth of the carbides M_6C leads to the reduction of chromium in the matrix what results in reduction of solid solution strengthening and consequently in the recovery and recrystallisation of the matrix. The enrichment of MC carbides with molybdenum makes possible the nucleation on the interface boundary of MC carbide/acicular ferrite of M_2C type precipitations [14]. Above mentioned complexes created at the expense of MC carbides are referred to as „H – carbides" and may lead to the decrease in creep resistance of materials. Similar phenomenon has been observed in high-chromium steel designed for power generation industry where at the expense of fine-dispersed precipitations of MX type the complex nitride – Z phase is created. The Z phase formation contributes to the rapid decrease of creep resistance of those steels [15].

Precipitation processes on the grain boundaries and the increase in concentration of phosphorus in the region near the boundaries are the main reasons of the decrease in the impact resistance of low-alloy steel in case of long-term service at higher temperatures [16, 17]. Application of the tested steel in creep conditions apart from the reduction of steel strengthening with solid solution mechanism also results in the reduction of its strengthening with dislocation mechanism which is associated with the processes of recovery and recrystallisation of the matrix.

3.2. Hardness measurement

Hardness measurement was conducted in accordance with PN–EN 1043–1 [18] and PN–EN ISO 6507–1 standards [19]. Hardness was measured along two lines, approximately 2 mm from the upper surface of a weld face and approximately 2 mm from the lower surface of a weld root. The obtained results of hardness measurements are shown in Fig. 3. The measurements have revealed that average hardness for parent metal is approximately 202HV10, for HAZ – 287÷314HV10 and 348HV10 for a weld. Assuming the maximum hardness of 350HV10 for this material (joints in bainitic steel, no post-weld heat treatment) it was found that all obtained hardness results are lower than the acceptable ones. Simultaneously the hardness measurements of welded joint are comparable with those for homogenous joint in steel T24 prior to service (as welded, no heat treatment) [2, 5, 10].

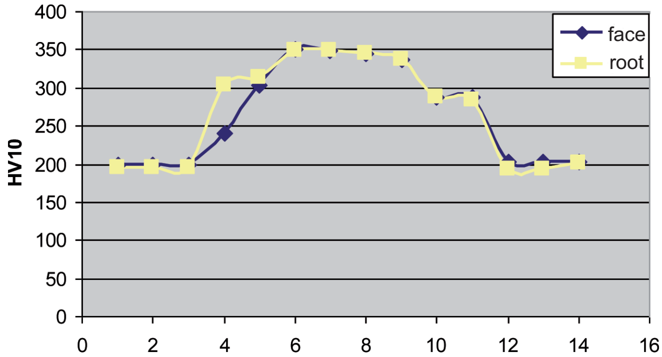

Fig. 3. Results of hardness measurement for tested joint

This indicates high stability of the microstructure of the tested steel and proves literature data [20, 21, 22] which reveal slower decrease in the mechanical properties compared to impact resistance during the service. Moreover high hardness of a weld after service and literature data [4, 18, 22] which show little decrease in the mechanical properties during the service make possible to find in a justified way that post-weld heat treatment is necessary in the case of those steels. Especially high yield point and tensile strength may correspond also to high hardness of a joint, what for low plasticity may favour cracking of a joint.

4. Summary

It has been tested homogenous welded joint in steel 7CrMoVTiB10 -10 (T24) sampled from the steam resuperheater coil pipe being in service for approximately 12 000 hours at temperature of 540°C and pressure 5.48MPa. Conducted testing has revealed the correct structure of a weld without any imperfections. A weld being in service in creep conditions contributed mainly to advantaged precipitation of carbides especially on grain boundaries – frequently in the contact area of three grains' boundaries (which is very unfavourable). Hardness measurements have revealed that they are comparable with the results obtained for the same joint type in the initial state (as welded). This indicates high stability of the microstructure as well as little influence of solid solution and dislocation strengthening on this parameter. Authors however have some reservation about high hardness of a weld after service, as it may indicate that its hardness in the initial state could have exceeded acceptable value of 350HV10. Therefore the authors' opinion about the necessity of post-weld heat treatment (stress relief annealing) in case of this steel or using a technique of tempering runs (if possible) is justified.

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