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The Analysis of the Post-Operation Microstructure and Mechanical Properties of the Similar Welded Joint

Abstract: The test material was a specimen sampled from sections of a pipe operated for 41,914 hours at a temperature of 575°C and under a steam pressure of 28.2 MPa. The specimen subjected to metallurgical tests was a welded joint made of austenitic steel TP347HFG. The non-destructive tests and the macroscopic tests confirmed the lack of any welding imperfections. The test joint represented quality level B in accordance with related standard requirements. The microstructural tests of the heat-affected zone (HAZ) revealed the presence of the fine-grained austenitic structure with numerous precipitates on grain boundaries – probably $M_{23}C_6$ carbides. In spite of long-lasting operation, the mechanical properties of the test welded joint were high and did not exceed the standard-related requirements concerning the base material.

Keywords: welded joint, steel TP347HFG, precipitates

DOI: *10.17729/ebis.2020.6/3*

Introduction

The future of Poland's power generation sector depends primarily on the implementation of new materials and technologies meeting increasingly high operational, economic and quality-related requirements when building power engineering systems. The above-named progress is stimulated by increasingly high EU requirements necessitating the reduced emission of pollutants into the atmosphere and, as a result, the increased efficiency of power units by increasing steam parameters (pressure and temperature). The adjustment of appropriate welding process parameters, i.e. low linear energy and a low heat input, enables the obtainment of welded joints characterised by appropriate mechanical properties [1, 2]. The research work discussed in this article aimed to analyse the effect of long-term operation on the microstructure and mechanical properties of a welded joint made in steel TP347HFG.

Test materials and methodology

A specimen subjected to metallurgical tests was a welded joint sampled from a steam superheater coil made of austenitic steel X8CrNi19-11 (TP347HFG) and subjected to a long-term operation of 105 000 h at a temperature of 540°C and under a pressure of 12.5 MPa. The tests included the following analyses and measurements:

- analysis of the chemical composition of the material subjected to the tests performed using a SpectroLab K2 spark emission spectrometer [3];

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- macroscopic tests involving the cross-section of the welded joints performed using an Olympus SZ61 light microscope;
- microstructural tests performed using an Axiovert 25 light microscope and a SEM Jeol JSM6610LV scanning electron microscope; the test joint was etched using the Mi19Fe metallographic reagent,
- Vickers hardness test performed using an FV–700 hardness tester (FutureTech) and a HV10 load of 98.1 N. Because of standard-related requirements, the hardness measurements were performed in two measurement lines, i.e. on the weld face side and on the weld root side [4];
- impact energy measurement performed using the standard specimens and Charpy V pendulum machine;
- static tensile test performed using a Zwick Roel Z100 testing machine.

The results of the analysis of the chemical composition of the base material are presented in Table 1. The results of the analysis of the chemical composition of the weld are presented in Table 2.

Macroscopic tests

The macroscopic image of the test welded joint is presented in Figure 1. The tests revealed that the structure of the joint was proper and free from any welding imperfections unacceptable in terms of quality level B in accordance with [5].

Table 1. Chemical composition of steel TP347HFG, % by weight

C	Si	Mn	P	S	Cr	Ni	Nb	N
0.09	0.47	1.56	0.023	0.003	18.38	11.19	0.61	0.04

Table 2. Chemical composition of the weld, % by weight

Si	Cr	Mn	Fe	Ni
0.71	18.82	1.59	68.41	10.48

Microstructural tests

Base material of steel TP347HFG

The base material on the side of steel TP347HFG was characterised by the fine-grained austenitic structure with the grain size amounting to 8/9 in accordance with the ASTM standard scale. In addition, the above-named structure contained annealing twins. The microstructure also contained large and numerous (locally arranged in laths) precipitates (Fig. 2). In accordance with

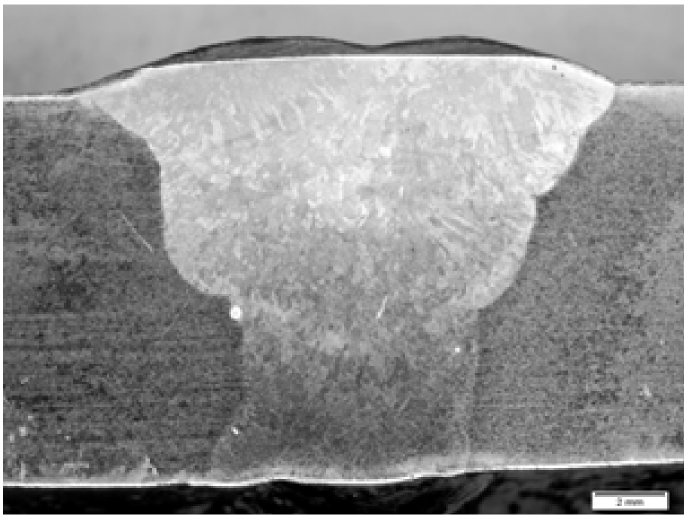

Fig. 1. Macroscopic image of the test welded joint

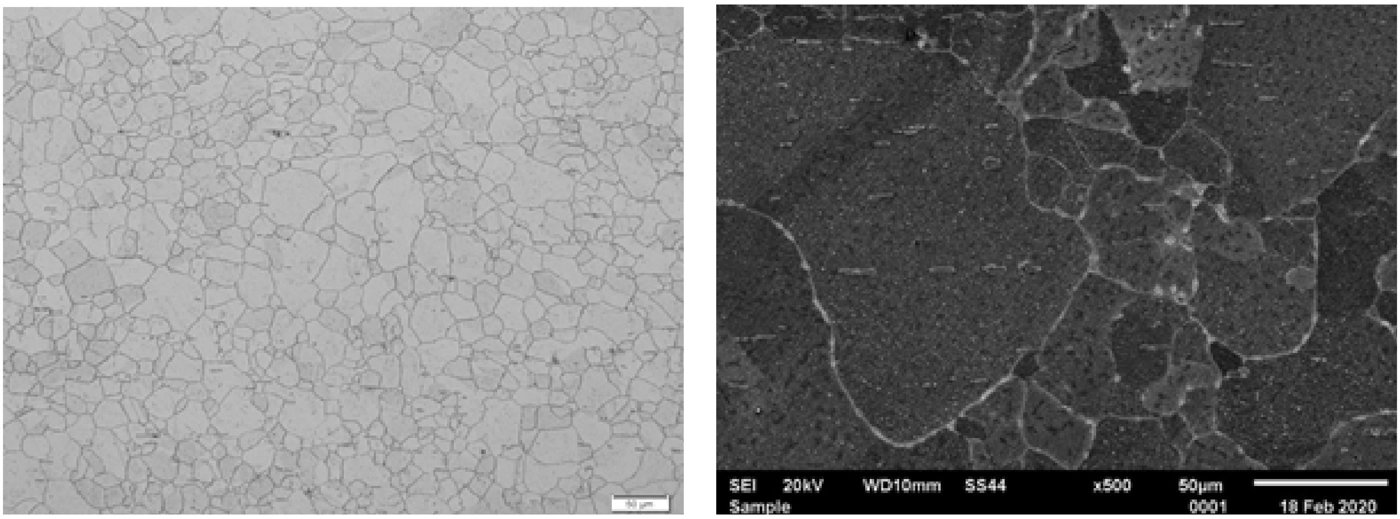

Fig. 2. Base material of the welded joint: a) OM, b) SEM

related reference publications [6], the above-named precipitates were NbC primary carbides. Because of the limited solubility of carbon in austenite, the microstructure of steel TP347H-FG may contain precipitates rich in chromium (M23C6), which located in large numbers along grain boundaries form the so-called "continuous lattice of precipitates" (Fig. 3).

HAZ structure

The microstructure of the HAZ near the fusion line on the side of steel TP347HFG (Fig. 3 and 4) was austenitic. The grain size amounted to 3 in accordance with the ASTM standard scale. Along the grain boundaries it was possible to notice fine and relatively numerous precipitates which, similar to the base material, formed the so-called "continuous lattice of precipitates". According to reference publications [7], M23C6 carbides precipitate along former austenite grain boundaries and along martensite laths in 9–12% Cr type steels. Because of their low thermodynamic stability, the aforesaid precipitates coagulate, leading to the reduced corrosion resistance and the oxidation of the steels [8].

Weld structure

The structure of the weld was similar to that of the HAZ, i.e. the austenitic microstructure containing numerous carbide precipitates along grain boundaries. Unlike the HAZ, the weld contained the coarse-grained structure (Fig. 5).

Tests of mechanical properties

The hardness measurement of the test joint (Fig. 6) made in two runs revealed that the area

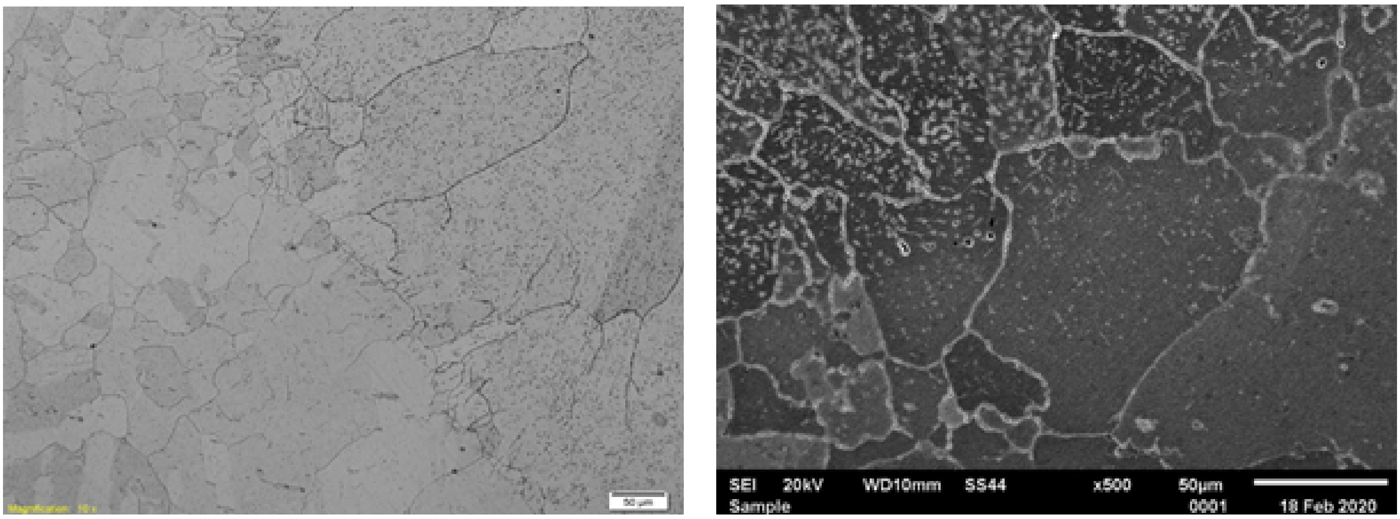

Fig. 3. Area near the fusion line of the welded join: a) OM, b) SEM

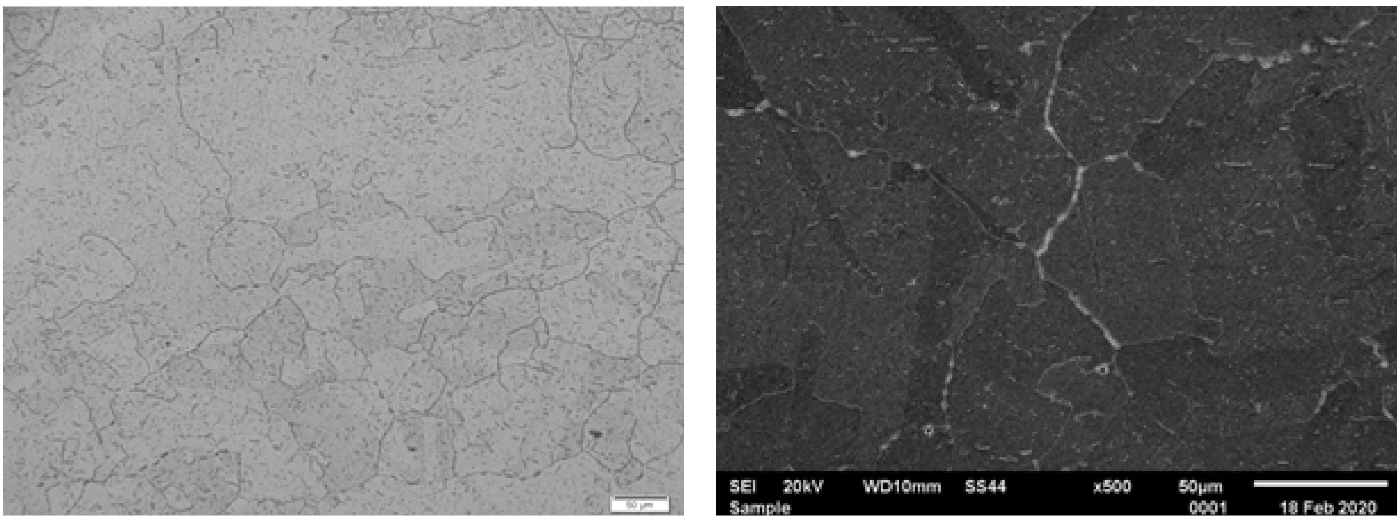

Fig. 4. HAZ in the welded joint: a) OM, b) SEM

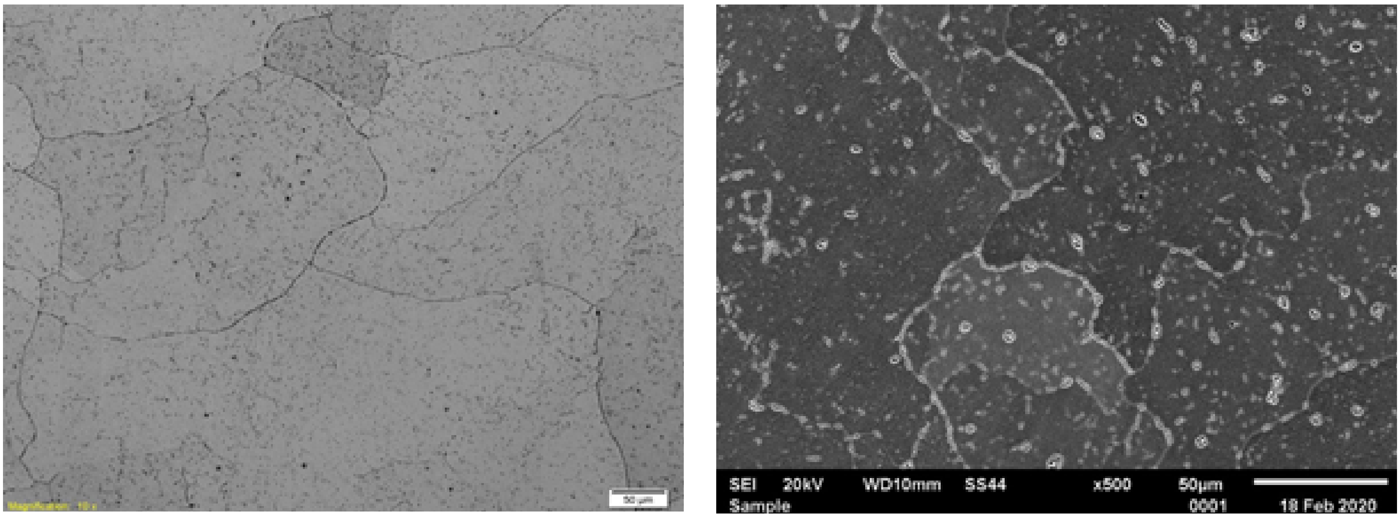

Fig. 5. Weld area: a) OM, b) SEM

characterised by the highest hardness was located on the weld face side. The hardness of the HAZ did not exceed the maximum value amounting to 350HV. The impact energy values of the test joint are presented in Figure 6. The highest impact energy value was observed in the HAZ, whereas the lowest value of impact energy was observed in the weld material. The aforesaid fact could probably be ascribed to varied size grains in the above-named areas (Fig. 7). The research work also involved the performance of a static tensile test which revealed that the welded joint was characterised by a high Rm value of 814 MPa.

Conclusions

The test material was a specimen sampled from a welded joint located on a pipe made in steel TP347HFG. Macroscopic tests revealed the lack of welding imperfections. As a result, the joint was classified as representing quality level B in accordance with related standard requirements. The HAZ microstructure, both within the grains and on grain boundaries, contained numerous eutectics, the presence of which could worsen the ductility of the material. The tests also revealed the presence of large primary NbC carbides as well as numerous secondary precipitates of M23C6 and NbC carbides. The cross-sectional hardness of the test joint did not exceed 350 HV. The mechanical properties, i.e. the tensile strength and the impact energy, of the test joint were high and exceeded the minimum values related to the base material.

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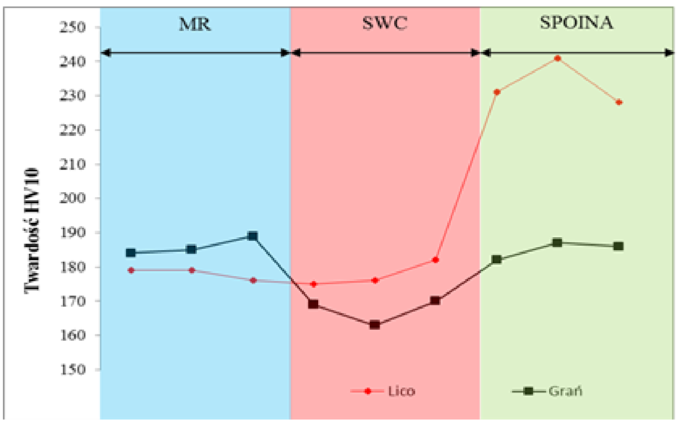

Fig. 6. Distribution of hardness in the cross-section of the test welded joint

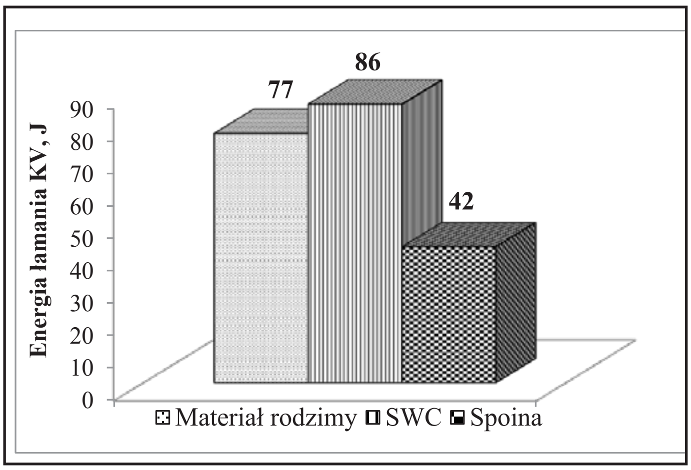

Fig. 7. Impact energy values

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