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HAZ MICROSTRUCTURE IN JOINTS MADE OF X13CrMoCoVNbNB9-2-1 (PB2) STEEL WELDED WITH AND WITHOUT POST-WELD HEAT TREATMENT

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Preliminary Note – Prethodno priopćenje

The article presents the results of research butt welded joints made of X13CrMoCoVNbNB9-2-1 steel. The joints were welded with post-weld heat treatment PWHT and without PWHT, using the temper bead technique TBT. After welding the joint welded with PWHT underwent stress-relief annealing at 770 °C for 3 hours. The scope of structural tests included the microstructural examination of the coarse-grained heat affected zone (HAZ) areas of the joints, the comparison of the morphology of these areas and the determination of carbide precipitate types of the coarse grain heat affected zone (CGHAZ) of the joints welded with and without PWHT.

Key words: welded joint, creep-resisting steel, heat affected zone (HAZ), microstructure, post-weld heat treatment (PWHT)

INTRODUCTION

The EU directive of 2001 [1] imposed the necessity of reducing pollutant emissions to the atmosphere and decreasing power generation costs, which directly entailed the necessity of increasing the efficiency of power plant units. In the last decade or so efforts have been undertaken in order to develop new grades of structural steels the mechanical properties of which, i.e. creep strength and heat resistance, would be high enough to enable the application of such steels at an even higher operating temperature [2]. An example of the search for new structural materials for power engineering is the European research project COST 536 which has led to the development of X13CrMoCoVNbNB9-2-1 grade experimental martensitic steel temporarily designated as PB2.

High-temperature steels are generally characterized by limited weldability. For this reason, after welding joints must be subjected to PWHT, conducted primarily in order to reduce welding residual stresses as well as to improve the plastic properties of a weld and those of a HAZ [3].

In industrial practice, particularly during repair welding usually carried out on large objects, conducting the PWHT of a joint can be accompanied by numerous difficulties. In situations when, due to technical reasons, conducting conventional heat treatment is limited or impossible, the use of the TBT is recommended [4, 5]. This technique consists of a specific manner and sequence of making individual beads in the weld so that a controlled thermal cycle can lead to the obtainment of the effect of tempering martensite formed during cooling both in the weld and in the HAZ of the welded joint [4, 5].

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EXPERIMENTAL AND RESULTS

The subject of the research included butt joints made of X13CrMoCoVNbNB9-2-1 (PB2) steel (external diameter of 219,1 mm and wall thickness of 31 mm). The chemical composition of PB2 steel is presented in Table 1.

The joints were welded using the following filler metals:

a) rods (2,4 mm in diameter) for tungsten inert gas welding (TIG) (method 141) grade – Thermanit MTS 616; and b) electrodes (3,25 mm in diameter) with a low-hydrogen coating for manual metal arc welding (MMA) (method 111) grade – Thermanit MTS 5 Co1.

Table 1 **Chemical composition of X13CrMoCoVNbNB9-2-1 (PB2) / wt%**

C	Mn	Si	P
0,135	0,31	0,076	0,0058
S	Ni	Cr	Mo
0,001	0,15	9,28	1,51
V	Co	Nb	B
0,19	1,33	0,053	0,0091

The joints were made in the following manner: the root run was welded using the TIG method, whereas filling runs and the weld face were MMA welded. A group I1 gas was used as the backing gas in the process.

Welding was conducted in the flat position (PA). Two test welded joints were made. One joint was welded conventionally, i.e. welding was followed by PWHT consisting of stress-relief annealing at a temperature of 770 °C for 3 hours. The second joint was made using the TBT without PWHT after the completion of welding.

Each welded joint was sampled for specimens for microscopic metallographic examinations performed following the requirements of the standard EN ISO 17639. The microstructure of the welded joints was revealed using $FeCl_3$. The exemplary microscopic metallographic test results (light microscope – LM) are presented in Figures 1 and 2. The detailed examination performed using a Nikon Eclipse MA200 inverted LM in combination with a computer provided with Nikon-developed NIS Elements-AR software revealed the presence of delta ferrite in the weld of the joint made using the TBT (Figure 2c).

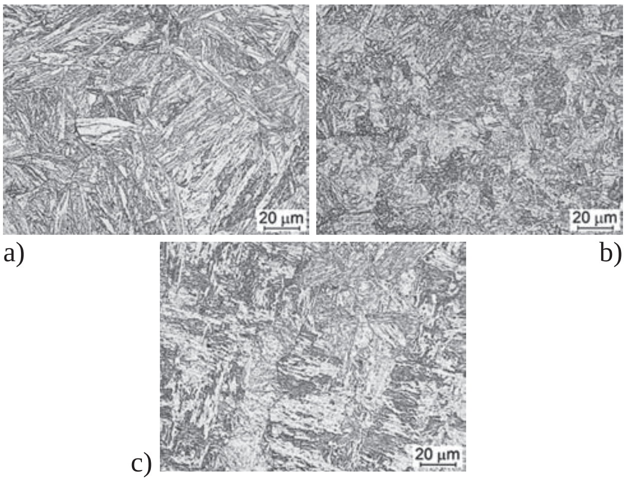


Figure 1 Microstructure of the joint subjected to PWHT: a) PB2 steel parent metal: tempered martensite; b) coarse-grained HAZ (CGHAZ): tempered martensite; c) weld: tempered martensite; etchant: $FeCl_3$, mag. 500x

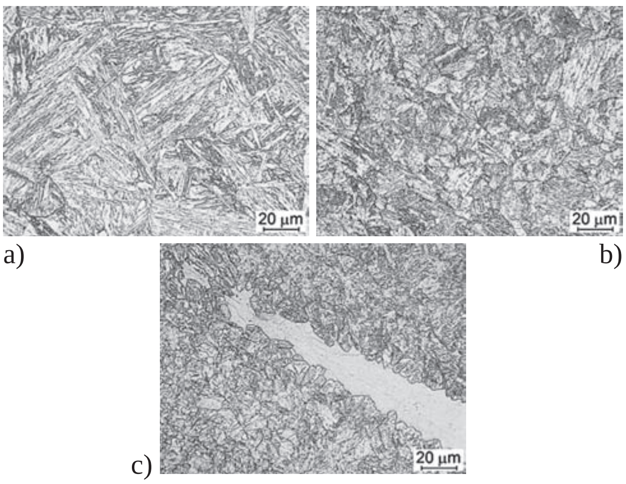


Figure 2 Microstructure of the joint not subjected to PWHT, i.e. welded using the TBT: a) PB2 steel parent metal: tempered martensite; b) CGHAZ: tempered martensite; c) weld: tempered martensite + delta ferrite; etchant: $FeCl_3$, mag. 500x

A more detailed microstructural analysis of the joints subjected and not subjected to PWHT was conducted using transmission electron microscopy (TEM).

The tests were conducted on specimens in the form of thin films using a JEOL JEM 200CX transmission electron microscope.

The tests of quantitative microstructure parameters (subgrain size, dislocation density inside subgrains) were carried out using AnaliSIS 3.1 software.

The example of the typical microstructure observed in the CGHAZ of the welded joint subjected to PWHT is presented in Figure 3, whereas the typical microstructure observed in the CGHAZ of the joint welded using the TBT is presented in Figure 4.

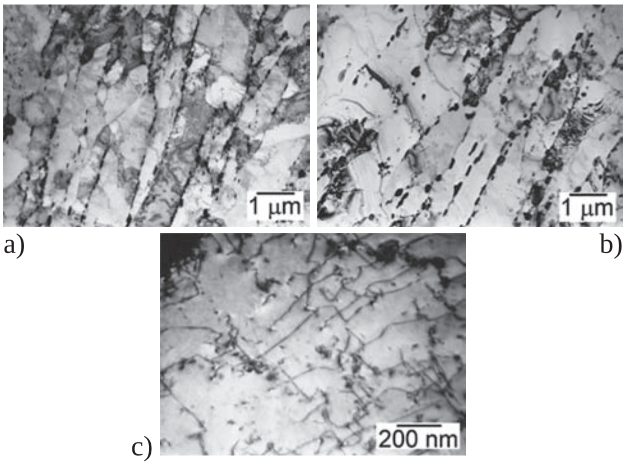


Figure 3 Microstructures observed on the thin films (TEM) in the CGHAZ area of the joint subjected to PWHT: a) general morphology of tempered martensite; b) morphology of ferrite subgrains; c) dislocation density in subgrains

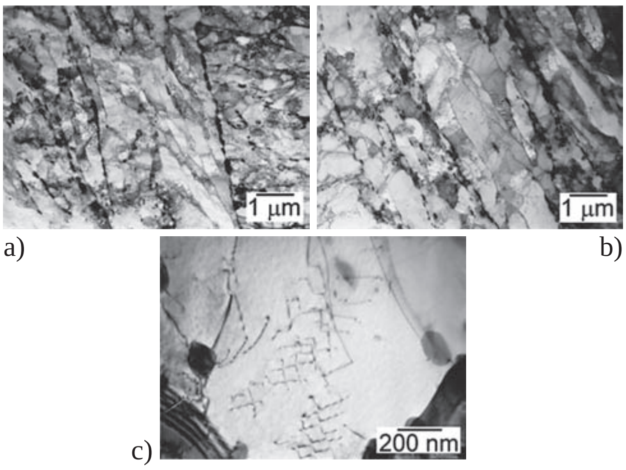
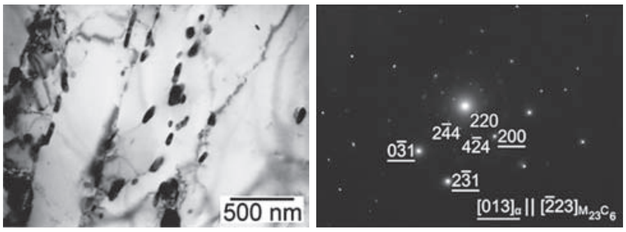


Figure 4 Microstructures observed on the thin films (TEM) in the CGHAZ area of the joint welded using the TBT: a) general morphology of tempered martensite; b) morphology of ferrite subgrains; c) dislocation density in subgrains

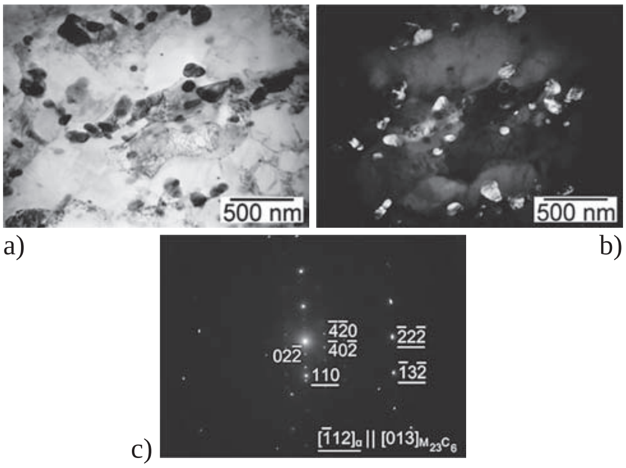
The measurement of dislocation density inside the subgrains revealed that for the CGHAZ area the dislocation amounted to $2{,}17 \pm 1{,}12 \times 10^{14}$ m^{-2}, whereas the CGHAZ area of the specimen welded using the TBT amounted to $2{,}42 \pm 0{,}98 \times 10^{14}$ m^{-2}.

The tests also involved the analysis of the types of precipitates of dispersive phases in the CGHAZ areas of the joint subjected to PWHT and of those welded using the TBT. The type of carbides was identified by means of SAED (selected area electron diffraction) analysis and through recording the microstructure in the dark visual field. Examples of the morphology of the observed $M_{23}C_6$, NbC and V(CN) carbide particles are presented in Figures 5–8. The size of the MX-type fine/dispersive precipitates was restricted within the 10–40 nm range.



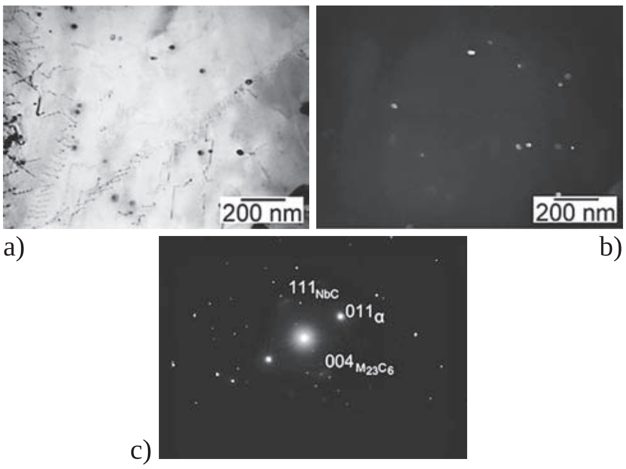
a) b)

Figure 5 Morphology of $M_{23}C_6$ carbides observed in the CGHAZ area of the joint subjected to PWHT: a) bright visual field; b) SAED diffraction pattern of $M_{23}C_6$ carbides: $[013]_{\alpha}||[223]M_{23}C_6$



a) b) c)

Figure 6 Morphology of $M_{23}C_6$ carbides observed in the CGHAZ area of the joint welded using the TBT: a) bright visual field; b) dark visual field; c) SAED diffraction pattern of $M_{23}C_6$ carbides: $112\alpha||[013]M_{23}C_6$



a) b) c)

Figure 7 Morphology of NbC carbides observed in the CGHAZ area of the joint welded using the TBT: a) bright visual field; b) dark visual field; c) SAED diffraction pattern of NbC carbides

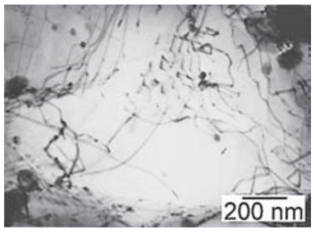


Figure 8 V(CN) (elongated) and NbC (spherical) precipitates in the CGHAZ area of the joint welded using the TBT

DISCUSSION

The microscopic metallographic tests conducted using a LM revealed that the parent metal of the X13CrMoCoVNbNB9-2-1 (PB2) steel of the welded joint subjected to PWHT and of the joint welded using the TBT contained tempered martensite (Figures 1a and 2a). The CGHAZ areas of both joint variants contained tempered martensite (Figures 1b and 2b). The weld microstructure of the welded joint subjected to PWHT contained only tempered martensite (Figure 1c). In turn, in addition to tempered martensite, the weld microstructure of the joint welded using the TBT contained delta ferrite and few areas of martensite only (Figure 2c).

The structural tests conducted using a TEM revealed that the CGHAZ microstructure contained the tempered martensite structure of elongated subgrains the shape of which had been 'inherited' from lath martensite and significant dislocation density inside the subgrains. On the boundaries of former austenite grains, on the subgrain boundaries and inside the subgrains, it was possible to observe numerous secondary phases of diversified morphology. The typical microstructures observed on thin films in the welded joints are presented in Figures 3 and 4. The quantitative tests of the microstructure on thin films revealed that a greater dislocation density was present in the CGHAZ area of the joint welded using the TBT (Figure 4c) in comparison with the analogous area of the welded joint subjected to PWHT (Figure 3c). In addition, the CGHAZ area in the joint welded using the TBT (Figure 4b) was characterized by a smaller size of subgrains compared with the welded joint subjected to PWHT (Figure 3b). However, it should be emphasized that the differences were insignificant. Such results may indicate the smaller tempering effect of welding heat coming from the subsequently made bead than that of PWHT.

The analysis of dispersive precipitates revealed that the CGHAZ area of the joint subjected to PWHT and that of the joint welded using temper beads contained two types of carbides, i.e. complex $M_{23}C_6$ carbides (Figures 5 and 6) and very fine/dispersive MX-type precipitates, where X stood for carbon and nitrogen atoms. The size of these precipitates did not exceed approximately 40 nm. The quantitative tests of the $M_{23}C_6$ carbides in the CGHAZ area revealed that in the joint subjected to PWHT these carbides were more fine/dispersive and elongated (Figure 5a) when compared with the carbides of this type present in the joint welded using the TBT (Figure 6a). These differences can be ascribed to the propelling force of the carbide nucleation process and to the carbide growth caused mainly by the temperature range in which they can precipitate. It should be mentioned that the hold time during the stress-relief annealing is short and should not lead to any noticeable changes in the size of the relatively stable carbides.

CONCLUSIONS

On the basis of the tests conducted it was possible to formulate the following conclusions:

1. The coarse-grained HAZ (CGHAZ) area in the joint welded using temper beads is characterized by greater dislocation density and smaller size of subgrains in comparison with the analogous area of the welded joint subjected to PWHT.

2. The CGHAZ areas of the joints subjected to heat treatment and those not subjected to PWHT contain $M_{23}C_6$ carbides, very fine/dispersive NbC carbides and V(CN) carbonitrides.

3. The $M_{23}C_6$ carbides present in the CGHAZ area of the welded joint subjected to PWHT are more fine/dispersive and elongated when compared with the carbides of this type present in the joint welded using temper beads.

4. The differences in the microstructure of the CGHAZ area affect the creep resistance of the joints tested. The joint welded using temper beads is characterized by a more advantageous dislocation structure and less advantageous carbide dispersion. Nevertheless, the technology can fulfill its role when it is not possible to use post-weld stress-relief annealing.

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