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PRACTICAL EXPERIENCE WITH WELDING NEW GENERATION STEEL PB2 GRADE ASSIGNED FOR POWER INDUSTRY

DOŚWIADCZENIA PRZY SPAWANIU ZŁĄCZY DOCZOŁOWYCH RUR Z NOWEJ GENERACJI STALI W GATUNKU PB2 PRZEZNACZONEJ DLA PRZEMYSŁU ENERGETYCZNEGO

This paper presents a new generation steel PB2 grade assigned for the power industry. In this article the authors present the results of non-destructive (VT, PT, RT) and destructive (tensile test, bending test, hardness measurements, impact strength, macro- and micrograph, fractography) tests. The major objective of the examinations was to verify properties of welded joints made of PB2 steel. Investigation of welded joints made of PB2 steel was performed in Instytut Spawalnictwa in Gliwice and it brings one of the first positive results for this type of steel in the world.

Keywords: martensite PB2 steel, pipe butt welds, new steel grades, welding

W artykule scharakteryzowano stal nowej generacji w gatunku PB2 przeznaczoną dla przemysłu energetycznego. Zaprezentowano wyniki badań nieniszczących (VT, PT, RT) i niszczących (statyczna próba rozciągania, próba zginania, pomiar twardości, pomiar pracy łamania, badania metalograficzne makro- i mikroskopowe) mające na celu sprawdzenie własności połączeń spawanych wykonanych z tego gatunku stali. Badania połączeń spawanych rur ze stali PB2, przeprowadzone w Instytucie Spawalnictwa w Gliwicach są jednymi z pierwszych wyników badań tej stali na świecie.

1. Introduction

A continuous trend aimed to reduce pollutant emissions to atmosphere and lower power generation costs is directly related to increasing efficiency of power units in conventional power stations. An increase in efficiency is obtained through boosting key working parameters i.e. steam pressure and temperature. Currently applied martensitic steels such as P92 make it possible to design power stations in which the temperature of superheated steam may reach as much as 625°C. Obtaining higher parameters can be possible only through continual search for modern materials used in fabrication of boiler and pipeline elements. This necessity has provided a stimulus to start studies of new steel grades, whose mechanical properties and creep resistance can be high enough for use in boiler elements operating under even higher parameters [1].

Many years of research has brought in many new steel grades with PB2 steel as one of them. This modern martensitic steel was developed within the framework of the European Research Programme COST 536. Due to the fact that the material is still under investigation, parallel efforts are being made to work out optimum parameters related to joint preparation, welding process and post-weld heat treatment. The parameters for the production of the joint described in the article were selected by the authors on grounds of available publications [2] as well as their own experience [3, 4, 5]. The welded joint was produced in Zakłady Elementów Kotłowych (Boiler Elements Factory) "ZELKOT" in Koszęcin, Poland.

2. Subject of investigation

The subject of the study was a pipe (ø 219.1×31 mm) made of PB2 steel, manufactured by Italy's Tenaris Dalmine. The chemical composition of the steel is detailed in Table 1. The mechanical properties of PB2 steel as delivered are presented in Table 2.

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TABLE 1

Chemical composition of PB2 steel as provided by manufacturer

Steel	Element content [%]									
designation	C	Mn	Si	P	S	Cr	Ni	Cu	Al	Ti
	0.135	0.31	0.076	0.0058	0.001	9.28	0.15	0.031	0.07	0.001
PB2	B	Nb	Mo	V	Co	As	Sb	Sn	N	–
	0.0091	0.053	1.51	0.19	1.33	0.002	0.005	0.004	0.026	

TABLE 2

Mechanical properties of PB2 steel as provided by manufacturer

Steel grade	Re [MPa]	Rm [MPa]	Amin. [%]
PB2	610	763	21.5

3. Filler metal

The research welding involved the application of Metrode-manufactured covered low-hydrogen electrodes (3.25 mm and 4 mm in diameter); the electrodes were developed for pipes and forgings made of B2 steel/cast steel. As PB2 steel has not been classified in standards yet, the aforementioned electrodes are not provided with designations pursuant to currently valid European Standards either. Electrodes Metrode Chromet WB2 were manufactured under specification AWS A5.5-96/ASME SFA 5.5 E9015-G [6]. The chemical composition of the filler metal is presented in Table 3.

4. Test joint production

The test joint was prepared for welding in accordance with Figure 1a. The root run was TIG-welded (141) using a solid rod for welding P92 steel. Today's market offer does not include solid rods for welding PB2 steels. The filling runs and face were welded manually with covered electrodes (111). The weld run sequence is presented in Figure 1b; the forming gas being argon. The welding was performed in the vertical up position (PF). Prior to welding the test elements were pre-heated up to approx. 200°C; during welding the inter-run temperature was constantly monitored. After welding the joint was cooled down to ambient temperature and next subject to stress relief annealing. The course of the whole welding thermal cycle and diagram of the post-weld heat treatment are presented in Figure 2.

TABLE 3

Chemical composition of filler metal as provided by manufacturer

Element content [%]													
C	Mn	Si	S	P	Cr	Ni	Mo	Nb	Cu	V	N	B	Co
0.11	0.59	0.19	0.008	0.011	9.22	0.66	1.46	0.04	0.03	0.22	0.023	0.006	1.02

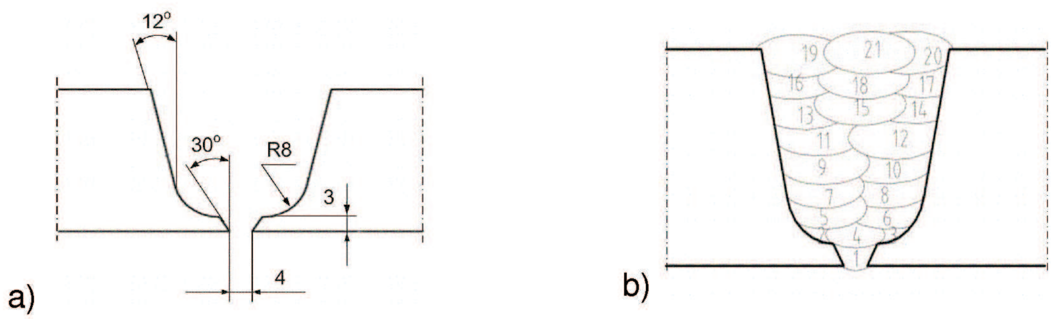


Fig. 1. Joint preparation diagram: geometry of weld groove (a), weld run sequence (b)

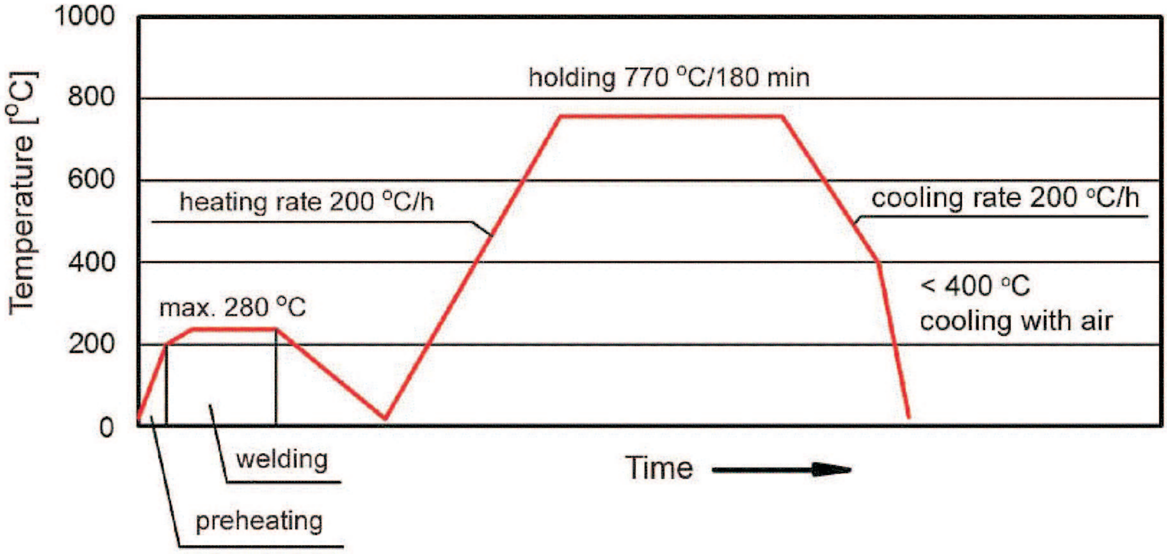


Fig. 2. Course of welding thermal cycle and diagram of heat treatment following welding of PB2 steel

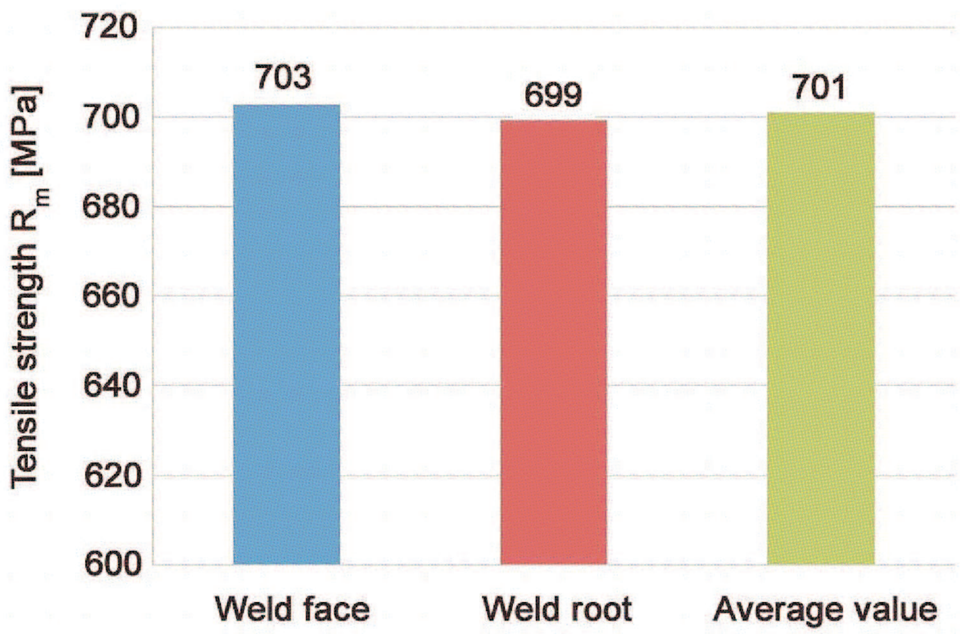


Fig. 3. Tensile strength of butt joint of pipes (ø 219.1×31 mm) made of PB2 steel

5. Testing procedure

The test weld was subject to non-destructive testing (visual VT, penetrant PT and radiographic RT). The quality level obtained according to standard PN-EN ISO 5817 [7] was that of B. Afterwards the joint was sampled for destructive testing. The scope of destructive testing included a static tensile test of welded joint, side bend test, impact test (notch cut in the weld, HAZ and parent metal), micro- and macroscopic metallographic examination and hardness measurements.

6. Welded joint tensile tests

The tensile strength of the welded joint (Rm) was determined using a testing machine INSTRON 4210 pursuant to standard PN-EN 895 [8]. The test results are presented in Figure 3; both specimens rupture outside the weld.

7. Impact tests of individual welded joint areas

The impact energy of the weld metal, HAZ and parent metal was tested using Charpy V samples pursuant to the requirements of standard PN-EN 12952-6 [9].

The standard specifies the minimum value of impact energy of HAZ using samples of normal cross-section (10×10 mm) as 24J at ambient temperature, whereas standard PN-EN 10216-2 [10] specifies the minimum value for parent metal (PM) as 27J for samples positioned crosswise in relation to pipe rolling. The results obtained in the test are presented in Figure 4.

8. Side bend test of welded joint

A side bend test of the weld was performed pursuant to the regulations of standards PN-EN ISO 15614-1 [11] and PN-EN 910 [12] using a bending mandrel of 60 mm – diameter. According to the standard [10] the positive criterion of a bending test is obtaining a bending angle of 180° without scratches or cracks on the stretched surface of the sample. The results obtained in the test (Fig. 5) meet the requirements of the aforesaid standard.

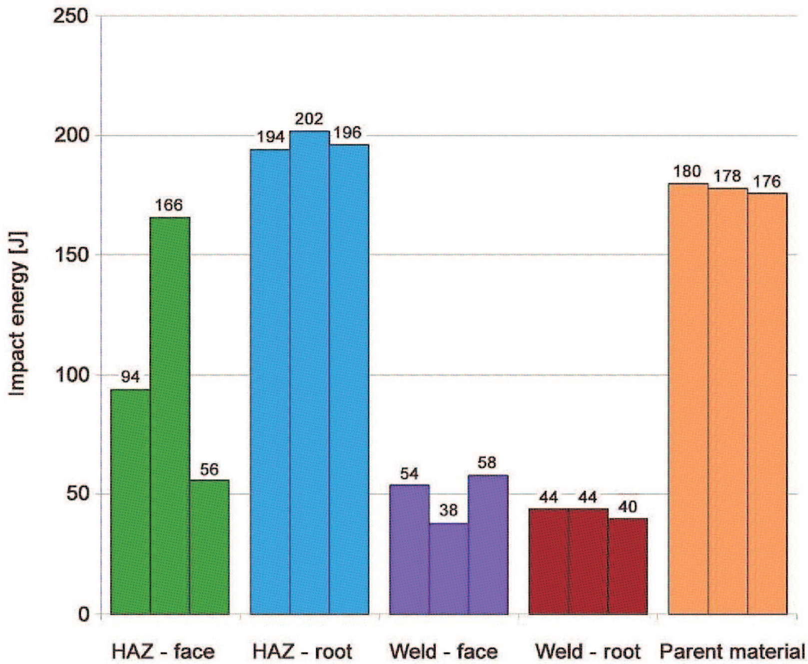


Fig. 4. Impact energy of weld, HAZ and parent material of butt joint of pipes (ø 219.1×31 mm) made of PB2 steel

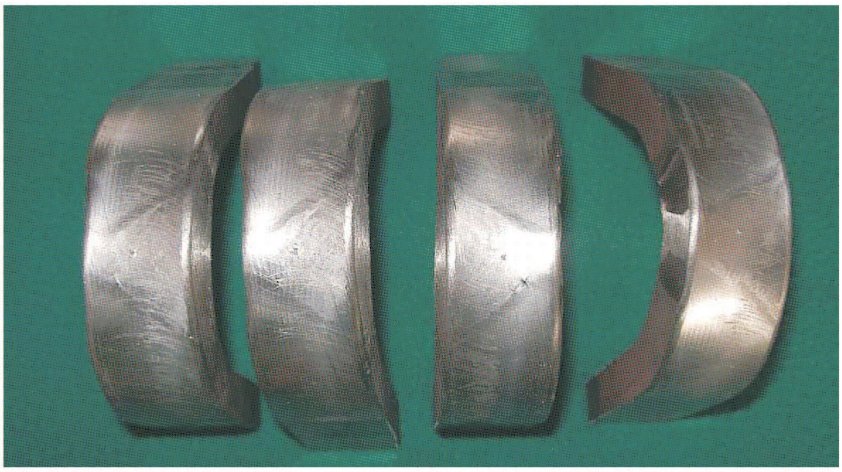


Fig. 5. Samples after side bend test of butt joint of pipes made of PB2 steel

9. Measurement of hardness of butt welded joint

The measurements were conducted using Vickers hardness test pursuant to the requirements of standards PN-EN 1043-2 [13] and PN-EN ISO 15614-1 [11]. As PB2 steel is not classified in standards yet, the criterion assumed in the tests was that for 6th material group after heat treatment i.e. the maximum hardness standing at 350 HV10. Figure 6 presents the arrangement of hardness measurement points, whereas Figure 7 contains the results of the related measurements. All the measurement results obtained values below the allowed 350 HV10.

10. Metallographic macro- and microscopic examination of welded joint

The examination was conducted pursuant to standard PN-EN 1321 [14]. The assessment criterion assumed for the test was quality level B according to the standard [11]; the test joint met the assumed requirement. The macrostructure of the test welded joint is presented in Figure 8.

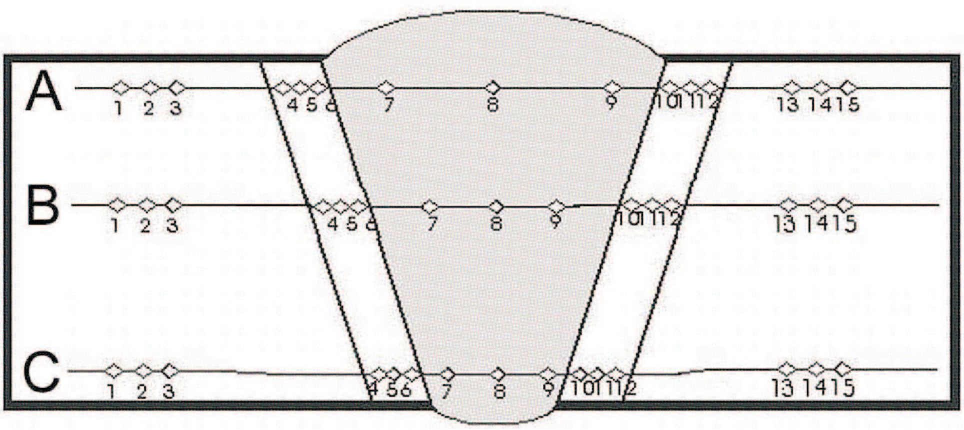


Fig. 6. Arrangement of hardness measurement points in welded joint

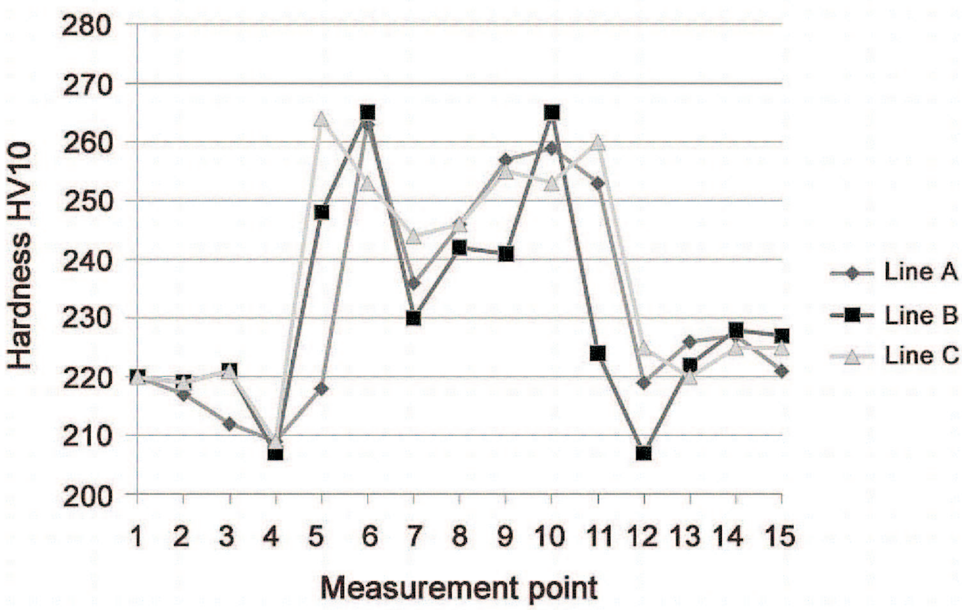


Fig. 7. Distribution of hardness in cross-section of welded joint of pipes (ø 219.1×31 mm) made of PB2 steel

Fig. 8. Macrostructure of butt joint made of PB2 steel; quality level B, Etch. Adler

The microscopic examination, conducted pursuant to the standard [14] revealed proper microstructure in individual areas of the butt joint made of PB2 steel. Table 4 contains the areas (marked) which were subjected to the microscopic examination as well as the results presented in the form of photographs and descriptions of the structures present in the characteristic areas of the welded joint.

11. Fractographic examination of welded joint

The fractographic examination was performed by means of a scanning electron microscope (SEM) with variable vacuum SEM VP S-3600N HITACHI combined with a THERMO NORAN-manufactured EDS X-ray spectrometer equipped with a System Six analyser. The observation focused on the surface of fractures following the hardness test. The examination incorporated secondary electron imaging (SEI) as well as backscattered electron imaging (BSE). Examples of weld fracture topography are presented in Figure 9.

The investigation also involved the analysis of the chemical composition of the weld made of PB2 steel and was performed with a Niton 898xlt spectrometer using X-ray fluorescence (XRF) technique. The results of the microanalysis of the chemical composition are presented in Figure 10, whereas the results obtained are detailed in Table 5.

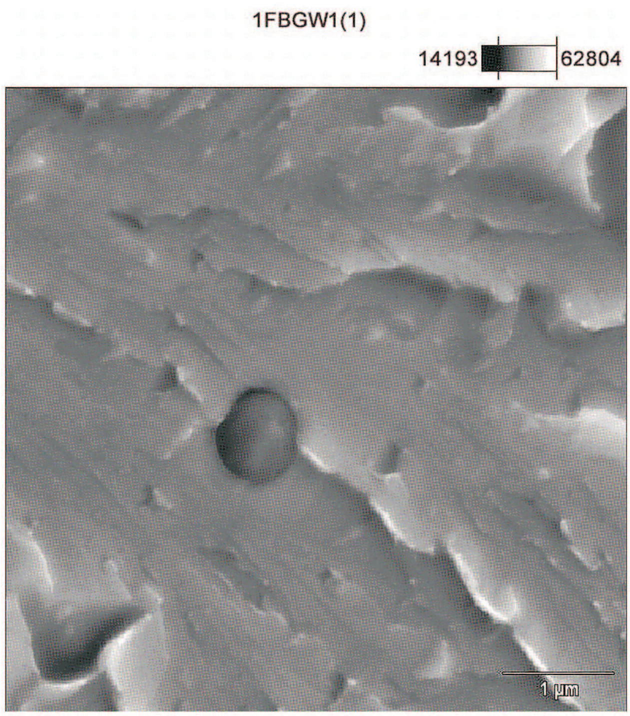
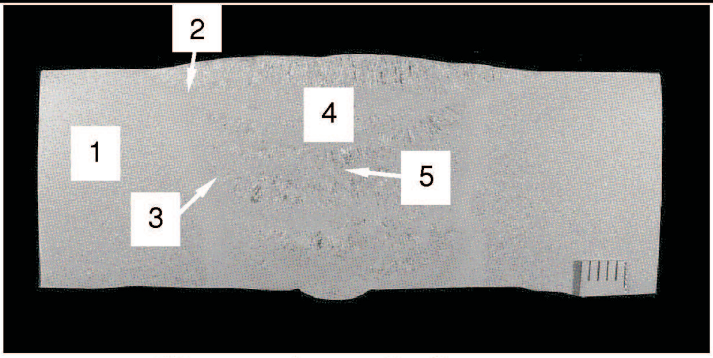


Fig. 9. Topography of fracture of weld made of PB2 steel

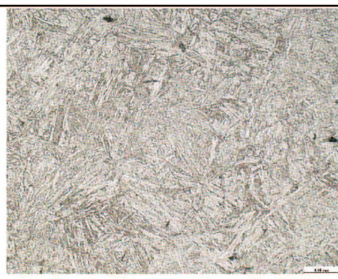
TABLE 4

Results of microscopic examination of butt joint of pipes made of PB2 steel



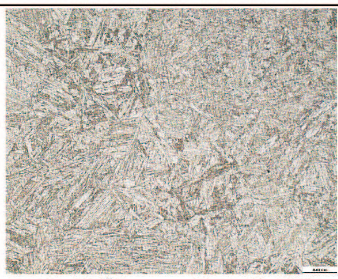
Microscopic examination areas

Area 1
Parent metal of PB2 steel
Tempered martensite



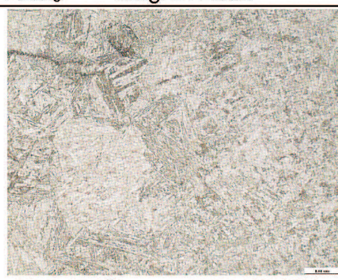
Etch. $FeCl_3$ Magnif. 200×

Area 2
HAZ
Martensite



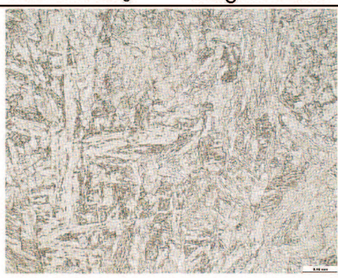
Etch. $FeCl_3$ Magnif. 200×

Area 3
HAZ
Martensite



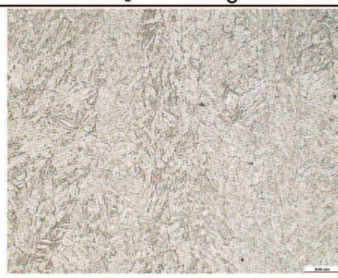
Etch. $FeCl_3$ Magnif. 200×

Area 4
Weld
Martensite



Etch. $FeCl_3$ Magnif. 200×

Area 5
Weld
Martensite
+ traces of
delta
ferrite



Etch. $FeCl_3$ Magnif. 200×

TABLE 5

Chemical composition of weld made of PB2 steel

Chemical composition of test welded joint										
Sb	Sn	Pd	Ag	Al	Mo	Nb	Zr	Bi	Pb	Se
0.00	0.06	0.00	0.07	0.00	1.50	0.03	0.00	0.00	0.00	0.00
W	Zn	Cu	Ni	Co	Fe	Mn	Cr	V	Ti	–
0.00	0.12	0.01	0.29	1.02	86.89	0.60	9.08	0.32	0.00	–

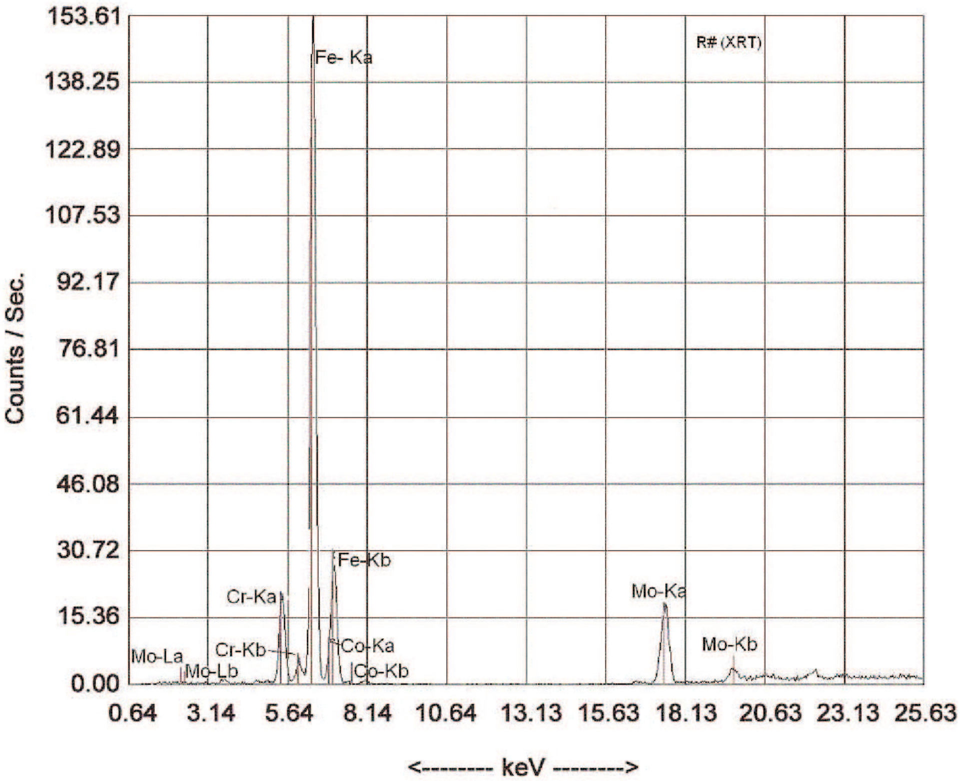


Fig. 10. X-ray radiation spectrum of PB2 weld

During fractographic examination both MC carbides and MX carbonitrides were found. Both precipitates were analyzed with chemical microanalysis and it was found that chromium carbides and vanadium carbides were present in weld and HAZ. According to known literature those precipitates positively affect creep resistance of martensitic steels and welded joints made out of steels like P92.

12. Conclusions

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

1. The butt joint of pipes ø 219.1×31 mm made of PB2 steel welded in a fixed position (PF) is characterised by high quality which was confirmed by destructive and non-destructive testing results.

2. The process of welding with a covered electrode is intense in character and the liquid metal of the weld pool spreads well on the walls of joined elements. The production of successive weld layers proves difficult as the fusion into previously made runs is problematic. The fabrication of similar joints made of P91 and P92 steels led to a conclusion that the aforesaid phenomenon is natural and does not impede the achievement of desired joint quality.

3. The fractographic analysis and the microanalysis of the chemical composition of precipitates in the weld reveals that the joint was produced properly and should meet the requirements of operation at increased temperature.

4. The positive findings of the mechanical tests justify optimistic expectations related to the application of the test steel in the power sector. However, the creep resistance of PB2 steel requires further research.

Acknowledgements

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