Testing of Welded Joints of Gas-Tight Pipe Walls Made of New Generation Martensitic Steel Type VM12SHC

Stanisław Lalik [1,a], Jarosław Adamski [2,b], Andrzej Balcerzyk [2,c]

[1] Silesian University of Technology, Material Science Department,
Krasińskiego 8, 40-018 Katowice, Poland

[2] Foster Wheeler Energy Fakop
Staszica 31, 41-200 Sosnowiec, Poland

[1,a] stanislaw.lalik@polsl.pl, [2,b] jaroslaw.adamski@fwpl.fwc.com, [2,b] andrzej.balcerzyk@fwpl.fwc.com

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Abstract. The paper presents the results of macro and microstructure testing and of hardness measurements of submerged arc welded joints of VM12SHC steel pipes (special high corrosion resistance, X12CrCoWVNbN12-2-2) with flat bars made of 10CrMo910 steel, intended for operation in elevated temperature. The tests were performed on welded joints that were not heat-treated and welded joints that were annealed (at 735-745°C for 0.5 hours) after welding. The results of the tests were used as a base to elaborate a Welding Procedure Specification.

Introduction

High-temperature creep-resistance properties of steel are developed on the basis of continuous modernization of chemical content that is supposed to ensure the best possible performances and increasing operating parameters. These requirements mainly concern: short/long-time creep resistance R_z and creep limit R_l, resistance to high-temperature corrosion, adequate ductility and crack resistance, high stability of microstructure and mechanical properties during long-time operation and good technological properties connected with welding, heat treatment and bending [1, 2, 3, 7].

VM12SHC steel is a martensitic steel developed and manufactured by Vallourec&Mannesmann. It is intended for membrane walls, chambers and pipelines operating at temperatures up to 650°C. The steel contains about 12% of chromium, and when compared to P92 or E911 steels, molybdenum was partially replaced with tungsten which was to increase creep-resistance by approximately 30% and to increase hardenability of steel, while a micro-addition of boron is intended to stabilize the $M_{23}C_6$ carbide. Chemical composition of the VM12 steel does not significantly differ from the previously used martensitic steels type P92 and E911. The only component that differentiates both types of steel is the amount of cobalt: WM12 contains much more of it. On this basis it is claimed that chemical composition of VM12 steel is modified, with chromium content of approx. 12% with alloy additions in the form of cobalt and tungsten ranging from 1 to 2% and micro-additions of niobium, nitrogen and boron [4, 5, 6].

Addition of cobalt to steel has an effect on the minimization of hardenability, and thus the increase the martensite start temperature. This makes it possible to successfully apply higher austenitization temperatures than before, without overheating. Due to the addition of cobalt to steel, it is possible to obtain the required martensitic structure after the heat treatment. During the tempering process, cobalt deters the loss of strength and hardness and decreases the parameter concerning the diffusion of other alloying additions. Moreover, due to the increased amount of precipitated carbides, the hardness of steel increases after tempering. Cobalt, being a strong austenite-generating element, decreases the amount of δ ferrites in the structure of high chromium steel. An important aspect of the introduction of cobalt in the amount of approx. 1.5% to the VM12 steel is the fact that it supports the increase of impact strength, creep strength, as well as decrease of temperature during transition into the brittle state [4÷9].

Material for tests

The tested joints were made of: the pipes made of VM12SHC steel (X12CrCoWVNbN12-2-2; ∅ 38 x 6.3 mm) and the flat bars made of 10CrMo910 steel (g = 6 mm). The chemical composition of the steels used to make the tested joints is shown in the Table 1. Submerged arc welding (SAW 121) was performed using welding wire OK Autrod 13.20 (EN 756: SCrMo2) ∅ 2 mm and the OK Flux 10.61 (EN ISO 14174: SA-FB165DC). Welded joints that were not subjected to heat treatment are marked as sample 1, the annealed welded joints are marked as sample 2. The materials were heated up to 200°C before welding. This temperature was maintained during welding and for 2 hours after welding.

Table 1. Chemical composition of a pipe of VM12SHC steel and flat bar of 10CrMo910 steel [mass %]

<table>
<tr><th>Steel</th><th>C</th><th>Si</th><th>Mn</th><th>P</th><th>S</th><th>Cr</th><th>Mo</th><th>Ni</th></tr>
<tr><td rowspan="3">VM12SHC</td><td>0.13</td><td>0.46</td><td>0.41</td><td>0.020</td><td>0.004</td><td>11.15</td><td>0.23</td><td>0.35</td></tr>
<tr><td>Cu</td><td>Al</td><td>Nb</td><td>V</td><td>N</td><td>B</td><td>Co</td><td>W</td></tr>
<tr><td>0.08</td><td>0.007</td><td>0.034</td><td>0.22</td><td>0.032</td><td>0.005</td><td>1.46</td><td>1.54</td></tr>
<tr><td rowspan="2">10CrMo910</td><td>C</td><td>Si</td><td>Mn</td><td>P</td><td>S</td><td>Cr</td><td>Mo</td><td>Cu</td></tr>
<tr><td>0.10</td><td>0.35</td><td>0.65</td><td>0.015</td><td>0.008</td><td>2.25</td><td>1.0</td><td>0.01</td></tr>
</table>

Tests results

Metallographic tests. The macro- and microstructure tests were performed on welded joints cut from a section of a membrane wall. The observations were performed on metallographic specimen that were selectively, chemically etched in a solution of nitric acid and hydrofluoric acid (pipes) and in nital (flat bar). The results of tests of the macrostructure of welded joints subjected to heat treatment are presented in Fig. 1 and of the microstructure – in Fig. 2-6.

Macroscopic tests of welded joints confirmed the correct structure of the joints that are free from welding non-conformities. Microscopic tests carried out on the base material of a pipe made of the VM12SHC steel revealed that the material has a microstructure of a highly tempered martensite with dispersive carbide precipitates and single non-metallic inclusions (Fig. 2). The martensitic structure with the precipitates of δ ferrite is present in the HAZ of the pipe (Fig. 4). The flat bar has a ferritic-bainitic structure with carbides (Fig. 3) and the grains within its HAZ have grown (Fig. 5). The weld has a dendritic structure (Fig. 6).

There are no welding macro- and microscopic nonconformities in the tested joints.

Hardness test. The Vickers hardness test was performed at a load of 49 N (HV5), in accordance with standards PN-EN ISO 6507-1 and PN-EN ISO 9015-1. The summary of hardness test results for welded joints without heat treatment and for welded joints after annealing is presented in Table 2. Hardness of welded joints after the heat treatment is significantly lower when compared to the non-treated joints. The highest hardness in the welded joints – both with and without heat treatment – was observed in the heat affected zone and in the weld. In case of welded joints without heat treatment, the hardness in heat affected zone of the pipes amounted to 447 HV5, while the hardness in the same heat affected zone of welded joints that were heat-treated was 332 HV5, maximum.

Fig. 1. Macrostructure of welded joint of VM12SHC steel

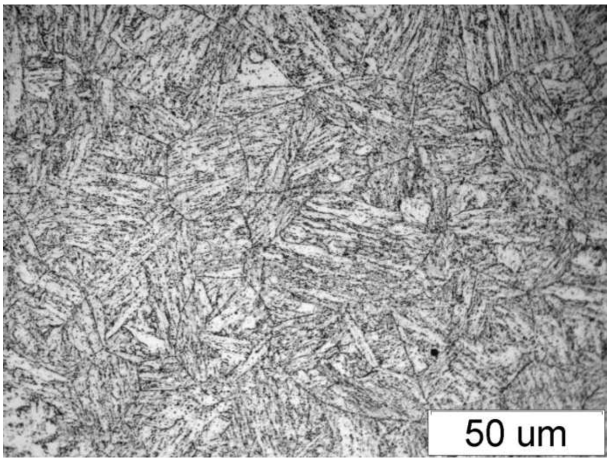

Fig. 2. BM microstructure of welded joint of VM12SHC steel

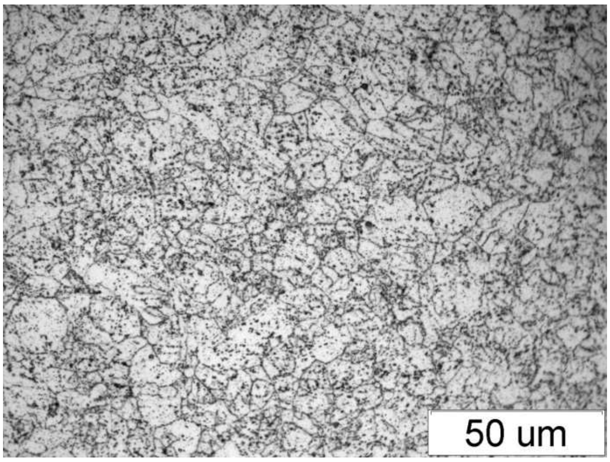

Fig. 3. HAZ microstructure of welded joint of HR3C steel

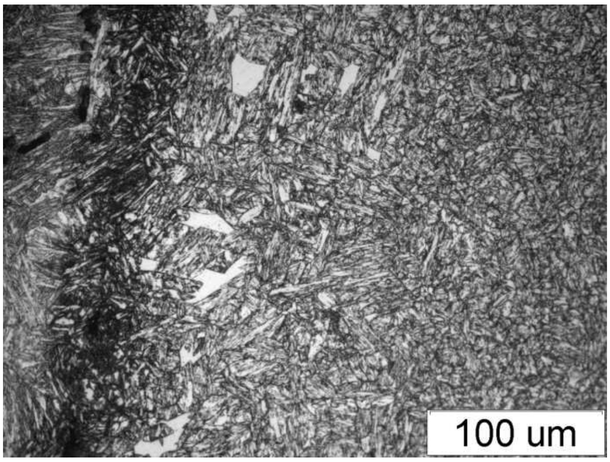

Fig. 4. HAZ microstructure of welded joint of HR3C steel

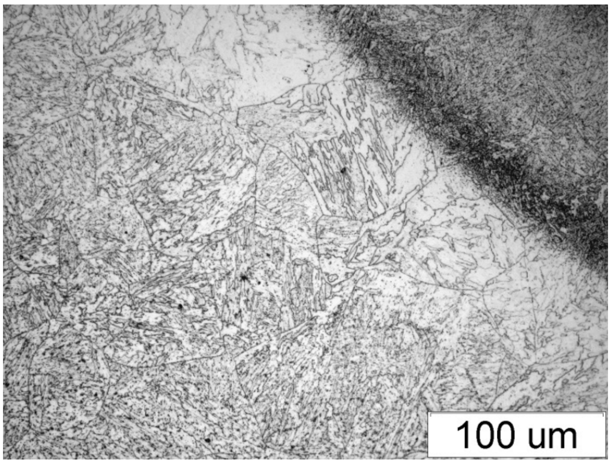

Fig. 5. BM microstructure of welded joint of 10CrMo910 steel

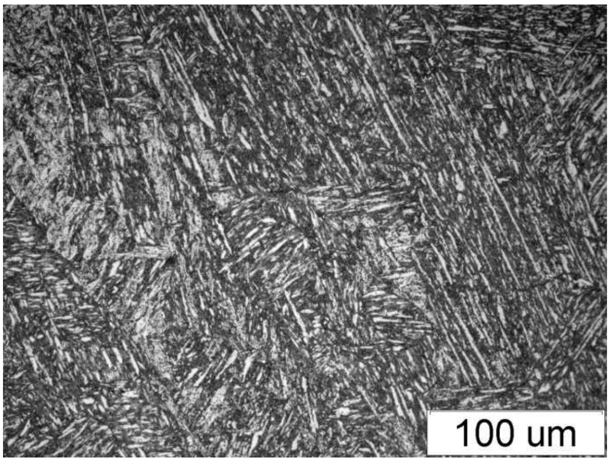

Fig. 6. Microstructure of welded joint of VM12SHC steel

Summary

Considering the results of tests that were performed we may conclude that the developed technology of submerged arc welding of gas-tight pipe walls made of the VM12SHC steel pipes and 10CrMo910 steel flat bars allows to obtain the joints that have correct geometry and are free from welding nonconformities. It was confirmed that there is a need of heat treatment after welding, making it possible to decrease the hardness of welded joints.

Table 2. Results of HV5 tests for welded joints of VM12SHC steel

Place of measurement	Weld 1	Weld 2	Weld 3	Weld 4
BM 10CrMo910	178, 181, 185 143, 147, 149	177, 187, 188 140, 1445, 148	179, 183, 170 141, 143, 146	188, 190, 184 144, 146, 149
HAZ 10CrMo910	289, 295, 285 232, 248, 262	298, 300, 304 248, 251, 258	289, 293, 290 241, 243, 251	309, 312, 298 144, 146, 149
Weld	393, 381, 359 268, 270, 274	380, 391, 383 274, 278, 283	345, 368, 379 218, 233, 270	395, 400, 397 277, 279, 293
BM VM12SHC	249, 246, 237 244, 249, 251	247, 241, 240 246, 248, 249	243, 244, 241 245, 245, 248	247, 249, 251 245, 245, 248
HAZ VM12SHC	418, 431, 447 294, 317, 320	425, 428, 415 283,286, 320	426, 430, 416 282, 294, 301	432, 436, 437 281, 313, 322

Note: upper row of the hardness measurement results - welds without heat treatment
lower row - welds after annealing at the temperature of 735÷745°C for 0.5 hours

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