Fabrication experience of new material for Power Industry – THOR 115

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ABSTRACT

Development of steels used in power generation industry for the production of boilers characterized by supercritical parameters poses new challenges. The introduction of new combinations of alloying agents aimed at obtaining the best possible mechanical properties, including creep resistance, affects the weldability of new steels. Each of the latter has to undergo many tests, particularly as regards bending and welding, in order to enable the development of technologies ensuring failure-free production and assembly of boiler systems. Martensitic steels containing 9% Cr, used in the manufacturing of steam superheaters, are characterized by good creep resistance and, at the same time, low oxidation resistance at a temperature in excess of 600°C. In turn, steels with a 12% Cr content i.e. VM12-SHC or X20CrMoV12-1 are characterized by significantly higher oxidation resistance, but accompanied by lower strength at higher temperatures, which translates to their limited application in the production of boilers operating at the highest parameters.

X20CrMoV12-1 was withdrawn from most of the power plants and VM12-SHC was supposed to replace it, but unfortunately, it failed in regards of creep properties. To fulfill the gap a new creep strength-enhanced ferritic steel for service in supercritical and ultra-supercritical boiler applications was developed by Tenaris and it is designated as Thor™115 (Tenaris High Oxidation Resistance). This paper covers the experience gained during first steps of fabrication which includes cold bending and welding of homogenous joints.

1. Introduction

The actual trend aimed at reducing power generation costs is closely related to increasing the efficiency of power units in conventional power plants. An increase in efficiency can be obtained by increasing key parameters like steam pressure and temperature. Today, obtaining higher parameters of steam boilers is possible only by applying modern steels and alloys able to bear increased operational loads and ensure high resistance at higher temperatures.

Modern martensitic steels such as P92 (X10CrWMoVNb9-2), make it possible to design power plant systems in which the temperature of superheated steam is 625°C. An increase in steam pressure and temperature has a direct effect on the operational conditions of boiler elements (esp. steam superheaters). 9%Cr martensitic steels are characterised by high creep resistance and moderate oxidation resistance at high temperature. In the past steel grade X20CrMoV12-1 was introduced to assure higher oxidation resistance but difficult fabrication and average creep properties forced the plants to replace it. Another approach was the VM12-SHC (X12CrCoWMoVNb12-2-2) with very good fabrication and oxidation properties but long term creep resistance was lower than estimated at the beginning. The latest introduction to the 9-12%Cr martensitic steel family is Tenaris High Oxidation Resistance steel named THOR™ 115 [1-4]

2. Object of tests

The object which underwent tests was a bent tube and a welded joint with an outer diameter of 50.8 mm, wall thickness of ca. 10.1 mm. The chemical composition of steels is presented in Table I. The tubes were welded with GTAW in 5G uphill position.

Table I. Chemical composition of examined steel acc. to MTR

Contents of chemical elements, %												
C	Si	Mn	Cu	Ni	Cr	Mo	N	V	Ti	Nb	P	S
0,09	0,15	0,47	2,75	0,15	10,78	0,51	0,042	0,24	0,002	0,034	0,016	0,002

The mechanical properties of tested steel in the initial state are presented in Table II.

Table II. Mechanical properties of tested steel acc. to producer's quality cert.

Mechanical properties					
Re, MPa	Rm, MPa	A, %	HV10	Re, MPa @ 650°C	Rm, MPa @ 650°C
615	681	27,5	224	214	255

After welding and bending, all specimens were subjected to stress relief annealing at a temperature of 760°C, for 60 minutes as per Figure 1.

3. Filler metals for welding

Unfortunately there is no dedicated filler available for welding of homogenous joints of Thor™ 115 and because of that in our research we have used three different filler metals: Grade 91, Alloy 82 and EPRI P87.

4. Schedule of tests

The production of the aforesaid welded joints was followed by non-destructive tests i.e. VT, PT and RT. The tests were carried out following the quality level B of the standard ISO 5817. After carrying out NDT tests, the test pieces were sampled for destructive tests.

The scope of destructive tests included:

- static tensile test of base metal (BM) and welded joints
- tensile test at elevated temperature
- bend test,

- impact test,
- macro- and microscopic metallographic tests,
- hardness measurements,

5. Results

TENSILE TESTS

The tests were carried out in order to determine the tensile strength (Rm) of a welded joint and confront obtained results with the minimum required value of (Rm) for the base metal (BM), which amounts to 620 MPa (specified by an ASME Code Case 2890 and VdTÜV WB580). The minimum value was marked with a red line in the graph (Figure 1). The static tensile test was carried out following the requirements of the standard ISO 6892-1 by means of a testing machine Instron 4210, provided with a computer-aided system of controlling and recording test results performed following the requirements of the standard ISO 4136.

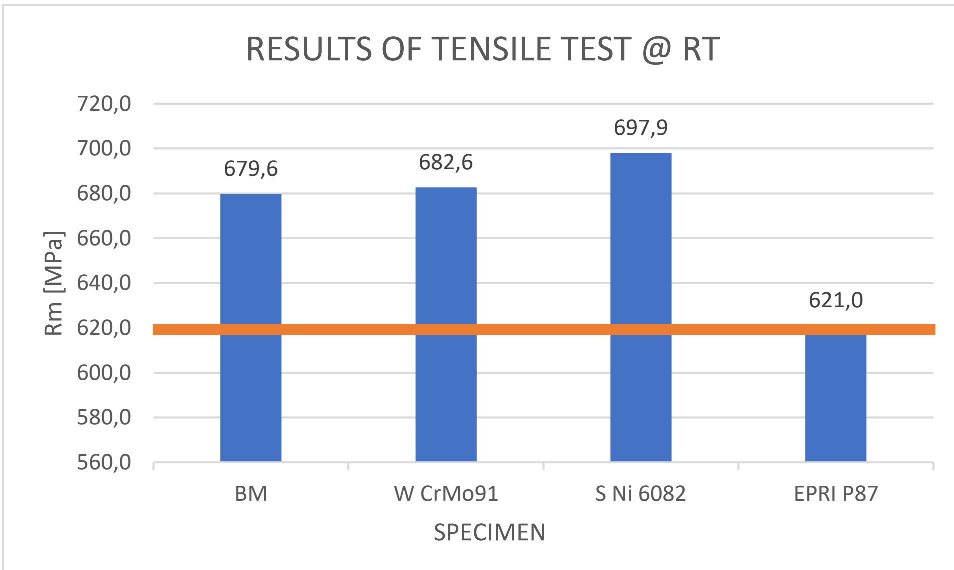


Figure 1. Tensile strength of butt joint of tube ø50.8x10,1mm made of steel grade Thor™ 115 welded with different filler metals.

TENSILE TESTS AT ELEVATED TEMPERATURE

The tests were carried out in order to determine the tensile strength (Rm) of a welded joint and confront obtained results with the minimum required value of (Rm) for the base metal (BM), which amounts to 190 MPa @ 650°C (specified by an ASME Code Case 2890 and VdTÜV WB580). The minimum value was marked with a red line in the graph (Figure 2).

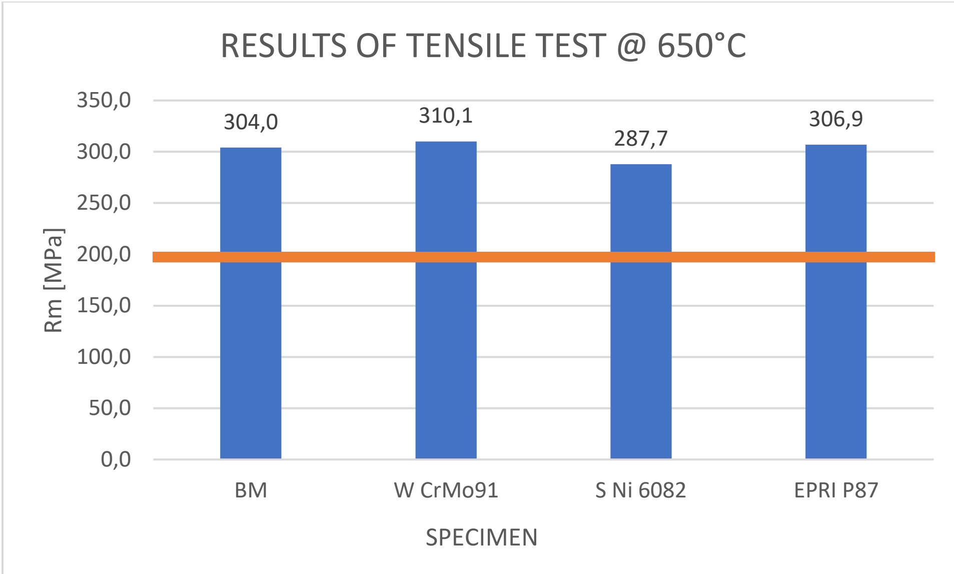


Figure 2. Tensile strength of butt joint of tube ø50.8x10,1mm made of steel grade Thor™ 115 welded with different filler metals @ 650°C

IMPACT TESTS OF WELDS AND HAZ

Impact tests were carried out in order to determine the values of impact energy for the weld and HAZ; they were performed at room temperature on test pieces with a Charpy V notch in the weld, HAZ and parent metal following the requirements of the standards ISO 9016 and EN 10045-1.

The criterion in the VdTÜV WB580 specifies that the minimum impact energy of test pieces of a typical section (10x10 mm) for the base metal should be 41 J. In the related graph (Figure 3), the value of 41J is marked with a green line.

The impact energy values obtained for the weld and HAZ are higher than those specified in the relevant standards. The tests were carried out on test pieces with a reduced section (5x10 mm), therefore the values presented in figures are, in fact, according to recommendations, proportionally higher. Figure 3 presents average values from three measurements.

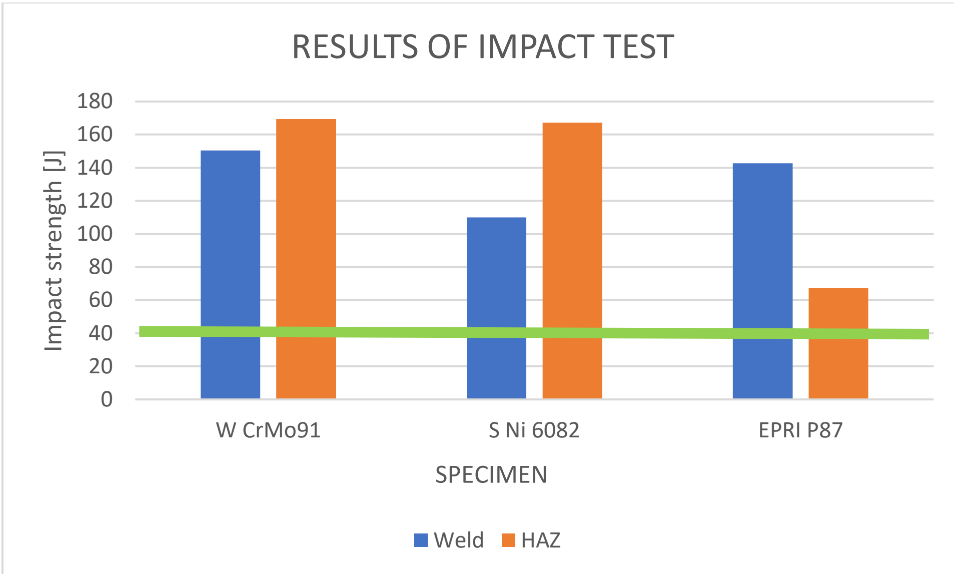


Figure 3. Impact energy of weld, HAZ and base metal in butt joints of tube ø50.8x10,1 mm made of steel grade Thor™ 115 welded with different filler metals.

BEND TEST

A bend test involving the tension of the face and the root of a weld was carried out following the requirements of the standards ISO 15614-1 and ISO 5173. In accordance with the standard ISO 15614-1, a criterion for the positive test is obtaining a bend angle of 180°, without scratches or cracks on the surface of a test piece being subjected to tension. The results obtained during the test meet the requirements of the standard.

HARDNESS MEASUREMENTS OF WELDED JOINTS

Hardness measurements were carried out following the requirements of the standards ISO 15614-1 and EN 12952-6. The aforesaid standards define the maximum hardness for martensitic steels at a level of 350 HV10. Schematic arrangement of measurement lines and points is presented in Figure 4. The results of measurements filler metals W CrMo91, S Ni 6082 and EPRI P87 are presented in Figures 5, 6 and 7 respectively.

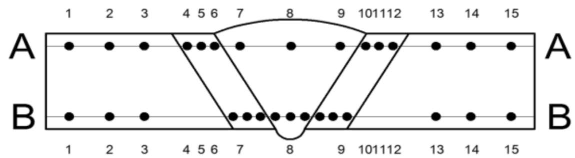


Figure 4. Arrangement of hardness measurement points in tested welded joints

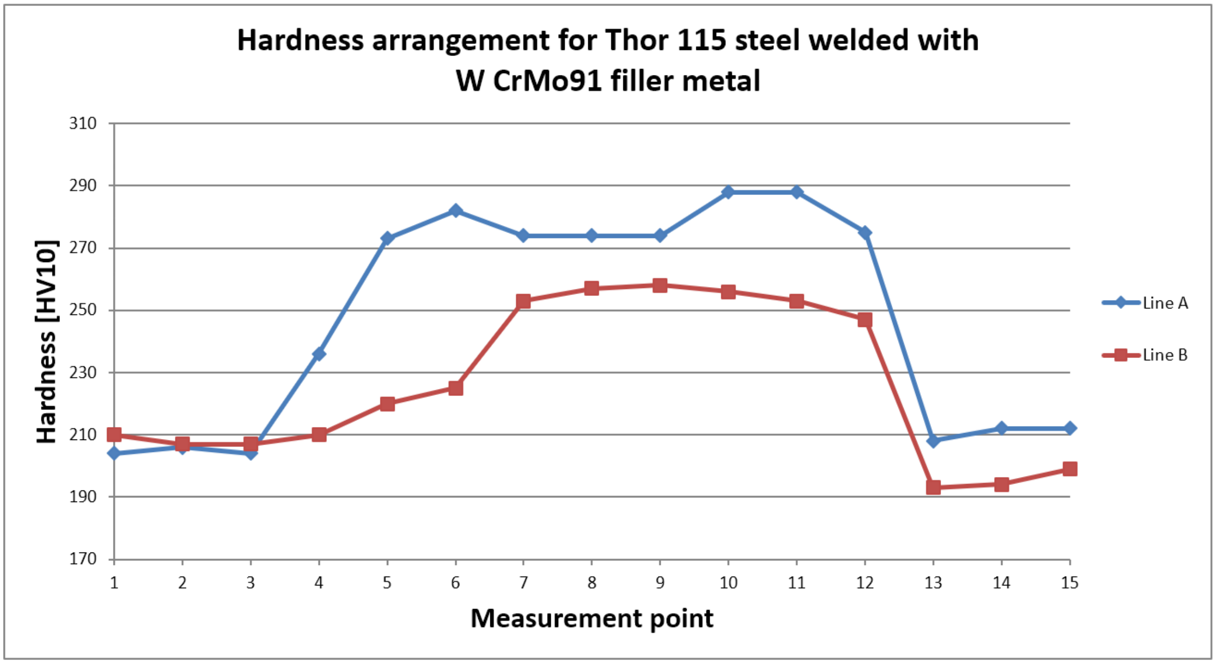


Figure 5. Results of hardness measurements of butt joint welded with W CrMo91 filler metal

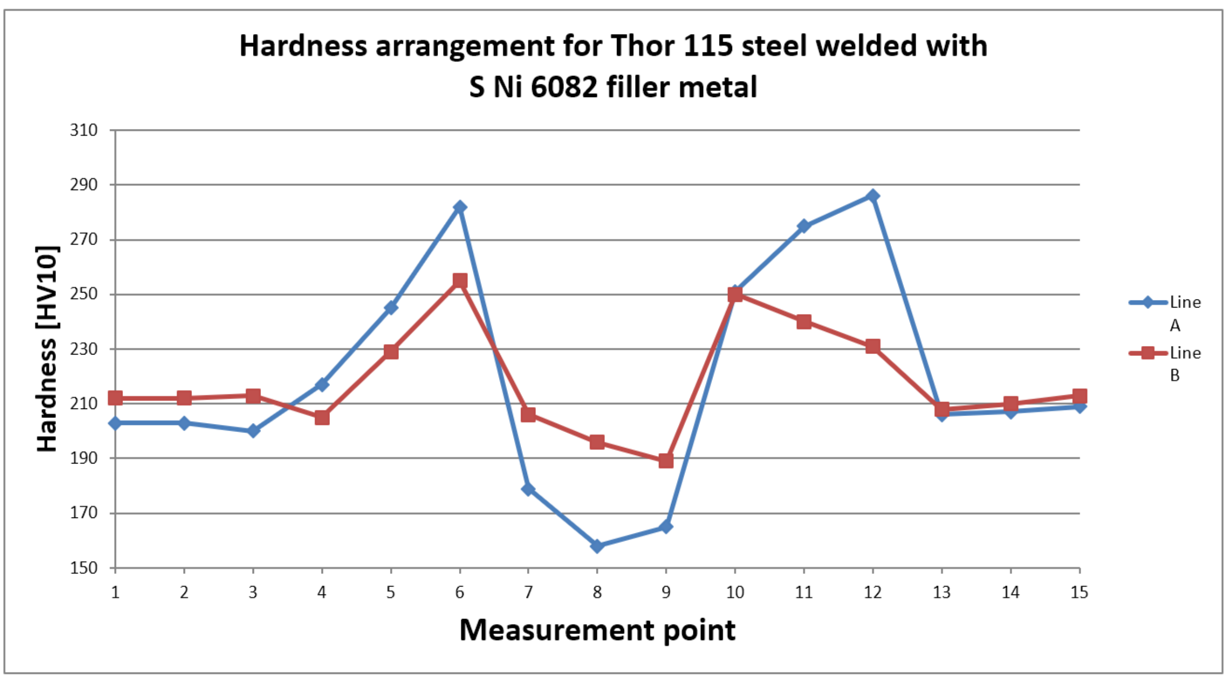


Figure 6. Results of hardness measurements of butt joint welded with Inconel 82 filler metal

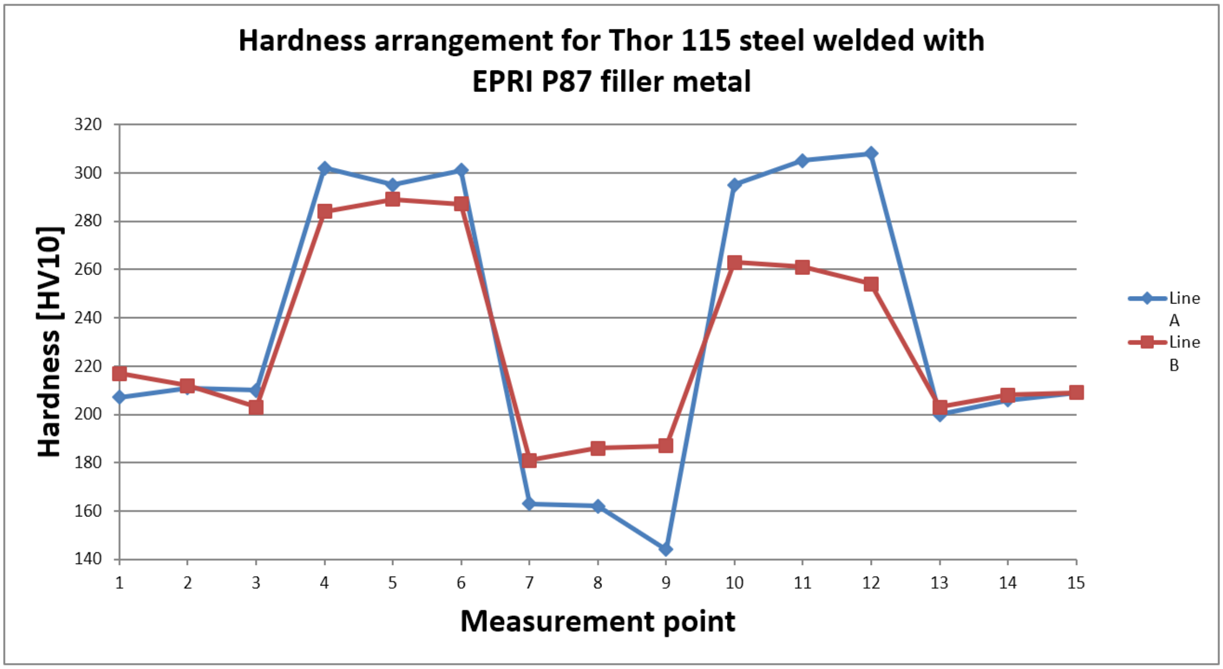


Figure 7. Results of hardness measurements of butt joint welded with EPRI P87 filler metal

MACROSCOPIC METALLOGRAPHIC TESTS

Macroscopic metallographic tests were carried out following the requirements of the standard EN 1321. A criterion adopted for assessment was the quality level B according to the standard ISO 5817, which was satisfied in case of the test joints. Figures 8, 9 and 10 presents the results of macroscopic tests in the form of a photograph of the microstructure of a GTAW butt joint made of steel grade Thor™ 115 welded with W CrMo91, Inconel 82 and EPRI P87 filler metals.

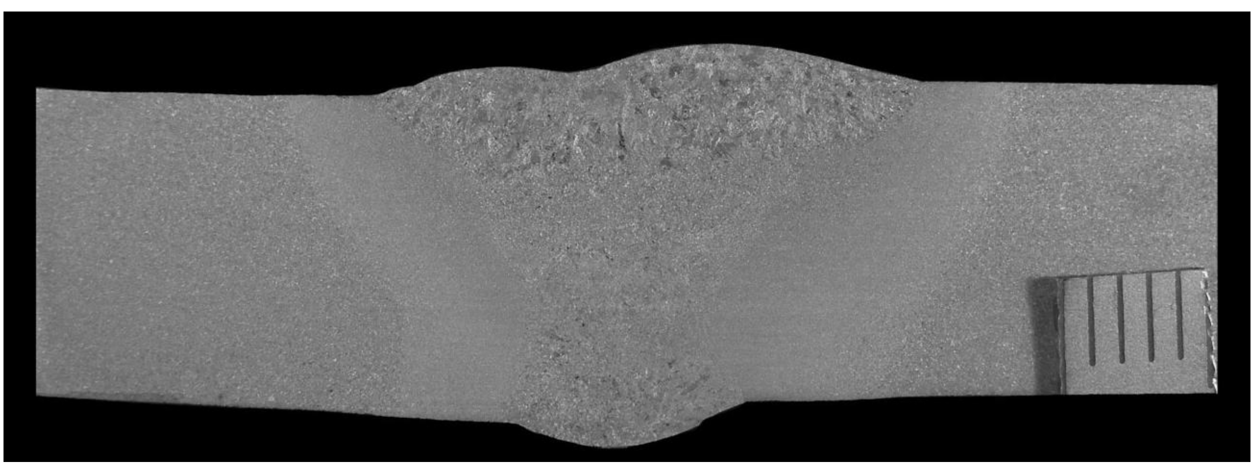


Figure 8. Thor™ 115 welded with W CrMo91 filler metal;
etchant: Nital; magnification 2x; quality level: B.

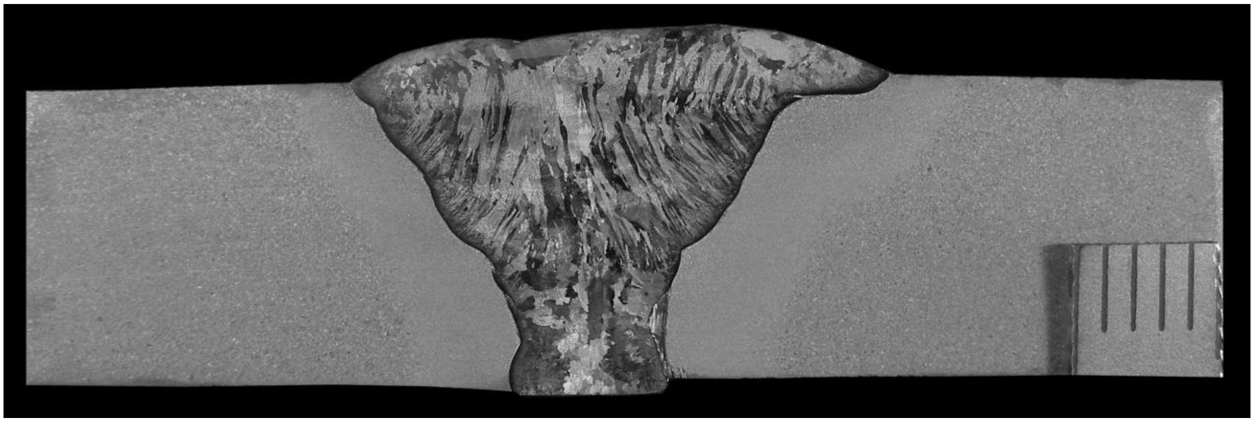


Figure 9. Thor™ 115 welded with S Ni 6082 filler metal; etchant: Nital; magnification 2x; quality level: B.

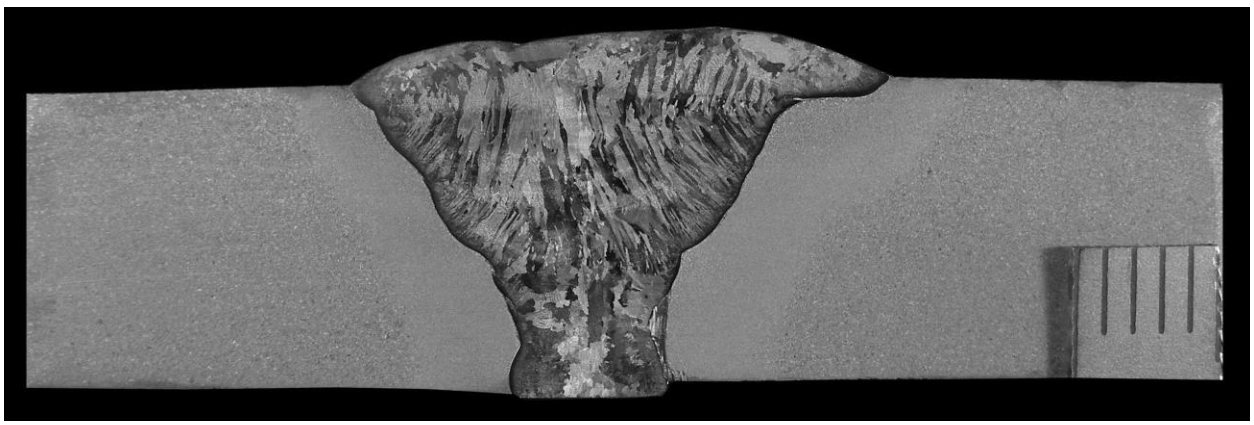


Figure 12. Thor™ 115 welded with EPRI P87 filler metal; etchant: Nital; magnification 2x; quality level: B.

MICROSCOPIC METALLOGRAPHIC TESTS

OM investigations were carried out following the requirements of the standard EN 1321. The results of the tests did not reveal any welding imperfections in the micro-scale and confirmed the existence of proper microstructure in all the zones. Tables IV, V and VI present the results of the microscopic tests in the form of photographs and descriptions of the structures identified in the characteristic zones of the welded joint.

Table IV. Thor™ 115 welded with W CrMo91 filler metal.

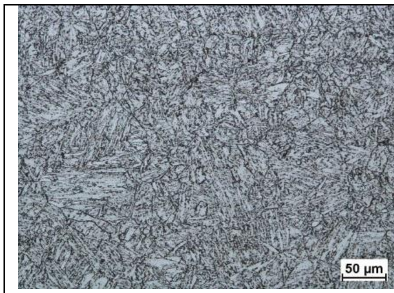
 base metal; electrolytic etching; mag. 200x, tempered martensite	 heat affected zone; electrolytic etching; mag. 200x, tempered martensite	 weld electrolytic etching; mag. 200x, tempered martensite

Table V. Thor™ 115 welded with S Ni 6082 filler metal.

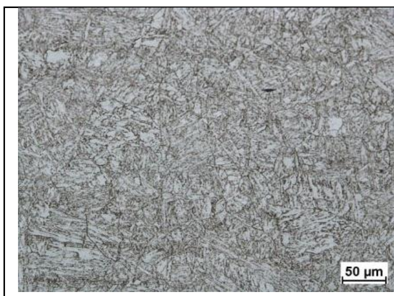
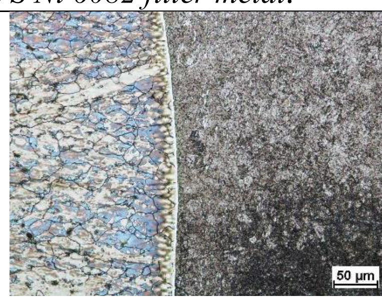
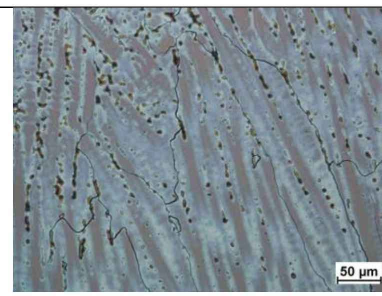
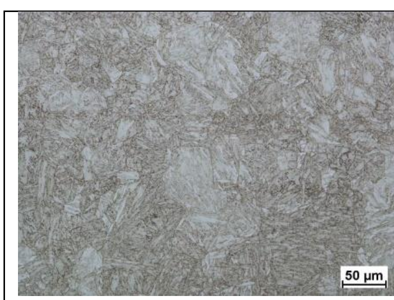
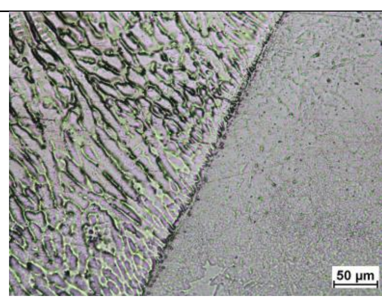
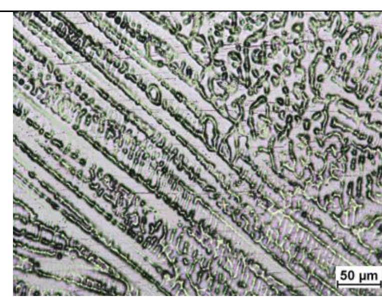
 base metal; electrolytic etching; mag. 200x, tempered martensite	 heat affected zone; electrolytic etching; mag. 200x, austenite-martensite transition zone	 weld electrolytic etching; mag. 200x, austenite

Table VI. Thor™ 115 welded with EPRI P87 filler metal.

 base metal; electrolytic etching; mag. 200x, tempered martensite	 heat affected zone; electrolytic etching; mag. 200x, austenite-martensite transition zone	 weld electrolytic etching; mag. 200x, austenite

6. Conclusion

On the basis of the aforesaid tests it was possible to come to the following conclusions:

1. Welded joints made of steel Thor™ 115, welded with GTAW in 5G uphill position are characterised by high quality, which is confirmed by the results of destructive and non-destructive tests.
2. Scheduled advanced microscopic tests and creep tests will enable a more detailed analysis of the joints and their industrial usability.

ACKNOWLEDGEMENTS

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7. References

[1] Urzynicok M., Kwieciński K., Szubryt M., Słania J.: Application of new GMAW welding methods used in prefabrication of P92 (X10CrWMoVNb9-2) pipe butt welds. 9th Liege Conference on Materials for Advanced Power Engineering, September 27th - 29th, Liege, Belgium, 2010

[2] Urzynicok M., Kwiecinski K., Slania J., Szubryt M., Mariani P.: Comparison of SMAW and GMAW Methods used in P92 Butt Welds. 1st Australasian International Welding, Inspection and NDT (iWIN2013) Conference, 10-13 March 2013, Perth, Australia

[3] Urzynicok M., Kwiecinski K., Szubryt M.: Testing butt joints in pipes made of VM12-SHC martensitic steel, Welding International, iFirst article 2012, 1-6

[4] Kwieciński K., Urzynicok M., Łomozik M.: Practical experience with welding new generation steel PB2 grade assigned for power industry. Archives of metallurgy and materials, Vol. 56, Issue 1, 2011

[5] Ortolani M., Baietta S., Escorza E.: New Generation Ferritic Steels for more Efficient Power Plants. PowerGen 2017

CODES AND STANDARDS USED:

1. ASTM A213 / A213M - 13: Standard Specification for Seamless Ferritic and Austenitic Alloy-Steel Boiler, Superheater, and Heat-Exchanger Tubes
2. ISO 5817: Welding - Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) - Quality levels for imperfections
3. EN 10216-2: Seamless non-alloy and alloy steel tubes for pressure purposes with specified elevated temperature properties
4. ISO 6892-1: Metallic materials - Tensile testing - Part 1: Method of test at room temperature
5. ISO 4136: Destructive tests on welds in metallic materials - Transverse tensile test

6. EN 12952-6: Water-tube boilers and auxiliary installations. Inspection during construction. Documentation and marking of pressure parts of the boiler
7. ISO 9016: Destructive tests on welds in metallic materials - Impact tests - Test specimen location, notch orientation and examination
8. EN 10045-1: Charpy impact test on metallic materials. Test method (V- and U-notches)
9. ISO 15614-1: Specification and qualification of welding procedures for metallic materials - Welding procedure test - Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys
10. ISO 5173: Destructive tests on welds in metallic materials - Bend tests
11. EN 1321: Destructive test on welds in metallic materials. Macroscopic and microscopic examination of welds
12. ASME Code Case 2890
13. VdTÜV WB580