ISSN 1330-3651 (Print), ISSN 1848-6339 (Online)
https://doi.org/10.17559/TV-20240810001912
Original scientific paper

Structural Integrity of Welded Joint between Steel Grades X10CrMoVNb9-1 and 12X18H12T

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Abstract: The two heterogeneous materials, austenitic stainless steel 12X18H12T and modified martensitic steel X10CrMoVNb9-1 (W.Nr.1.4903) are part of this experimental research. Both materials are used in boiler applications as structural materials and joints behaviour in service life is essential for structural integrity. The welds are made with nickel base electrode, NiCr20Mn3Nb according to EN ISO 18274 (Thermanit Nicro 82), first performing buttering layer of the martensitic steel, post weld heat treatment at 760 °C and welding with TIG process with austenitic steel. Mechanical testing was performed on the welds, tensile test, hardness measurement and microstructural analysis on base materials, heat affected zone, buttering layer, and weld metal. Tensile test showed that failure of the samples is on the austenitic side, on base material, indicating integrity of the weld joints. Microstructural analysis shows no cracks on critical regions, both the heat affected zone and fusion line region of martensitic steel and the weld metal.

Keywords: austenitic steel; dissimilar welded joints; martensitic steel; pressure parts; X10CrMoVNb9-1; 12X18H12T

1 INTRODUCTION

The development of new enhanced materials and new joint technologies and techniques enables reducing of harmful emissions of gases in the environment, reducing production costs, reducing the weight of construction, as well as improving the technical characteristics of materials. One of the reviewed enhanced materials in this paper is the martensitic steel X10CrMoVNb9-1 (1.4903) which is used in industries like power generation and petrochemicals [1-3].

Dissimilar metal welding, particularly between martensitic and austenitic steels, is essential in industries like power generation and petrochemicals. The X10CrMoVNb9-1, martensitic steel, offers excellent creep resistance, while 12X18H12T, austenitic steel, provides superior corrosion resistance. However, welding these materials presents challenges due to differences in thermal expansion, metallurgical compatibility, and mechanical properties. In this research paper mechanical properties and microstructural characterization are investigated between these two types of heterogeneous materials intended for work in high temperature applications.

Steam superheaters are pipe heating elements whose task is to superheat the steam in a dry saturated state to the required temperature. As structural elements of superheaters and collectors, these steel pipes often work in the most hazardous conditions, where the temperature of the steam reaches maximum value as well as the temperature of the metal [4]. The material works in high temperature conditions and is exposed to the product of combustion. The heating surface is thermally loaded and operates in non-constant temperature field. During operation, a large number of defects in steam boilers occur because of damage to the pipes of the steam superheaters, and the main reason is overheating and corrosion of the metal of the pipes. Any prolonged exceeding of the permissible temperature of the metal of the pipes leads to a shortening of the service life of the superheater.

2 MATERIALS FOR INVESTIGATIONS

The subject of investigation of this research paper is dissimilar metal weld intended to work in superheater section at working temperature of 600 °C and 30 MPa. One of the base materials is modified martensitic steel X10CrMoVNb9-1 classified according to EN10302-2008 [5] and used for header, pipelines for superheater steam, exchangers of heat under high pressure. The other steel is austenitic stainless steel classified according to GOST 5632-72[6], 12X18H12T, high temperature, corrosion resistant steel used for secondary steam superheater.

Chemical composition of the base materials is presented in Tab. 1 and Tab. 2.

Table 1 Chemical composition wt.% of the base material X10CrMoVNb9-1

C%	Mn%	Si%	P%	S%	Cr%
0.136	0.408	0.310	0.0454	0.0089	8.39
Ni%	Mo%	V%	Al%	W%	Ti%
0.0377	0.681	0.219	0.0078	0.00020	0.0028
Co%	Cu%	Fe%			
0.0119	0.0983	Bal.			

Table 2 Chemical composition wt.% of the base material 12X18H12T

C%	Mn%	Si%	P%	S%	Cr%
0.114	1.19	0.336	0.0692	0.0089	16.83
Ni%	Mo%	W%	Ti%	Fe%	
15.93	0.0579	0.0878	0.635	Bal.	

Mechanical properties of the base materials are presented in Tab. 3 and Tab. 4.

Table 3 Mechanical properties of X10CrMoVNb9-1

Base material 1 (BM1)	$R_{p0.2}$ / MPa	R_m / MPa	ε / %
X10CrMoVNb9-1	450	620÷850	min. 20

Table 4 Mechanical properties of 12X18H12T

Base material 2 (BM2)	$R_{p0.2}$ / MPa	R_m / MPa	ε / %
12X18H12T	216÷294	539÷686	35

3 EXPERIMENTAL WORK

For welding these two heterogenous materials, TIG141 process is used following ISO/DIS 4063:2020[7] and filler material NiCr20Mn3Nb according to EN ISO 18274 (Thermanit Nicro 82). The chemical composition of the filler material is given in Tab. 5.

Table 5 Chemical composition wt.% of the filler material

C%	Mn%	Si%	Cr%	Ni%	Nb%	Fe%
0.02	3.00	0.1	20.00	> 67.00	2.50	< 2

Due to the different chemical composition of the materials, martensitic steel X10CrMoVNb9-1 will encounter carbon diffusion due to the difference in Cr content. Carbon moves from the material with low Cr content to material with high Cr content. This decarburization zone is avoided with the use of nickel-base filler metal since carbon does not diffuse into the nickel-base material. The welding involves buttering the base metal (X10CrMoVNb9-1) with filler material using welding parameters such as preheating (250 °C) and post weld heat treatment (760 °C/2 h) suitable for the base material, Fig. 1 [8].

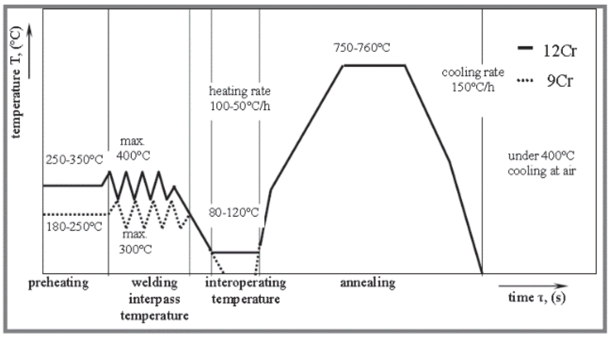


Figure 1 Temperature time cycle for X10CrMoVNb9-1 [5]

Figure 2 Buttering of base material

The buttering is used to deposit surfacing metal on the base metal surface to provide compatible weld metal for the completion of the weld, Fig. 2. The buttered layer of martensitic steel was deposited with filler material NiCr20Mn3Nb according to EN ISO 18274 (Bohler TIG rod Thermanit Nicro 82) with TIG welding process. The nickel electrode was used for buttering and welding process using argon gas shielding.

The PWHT is made according to the temperature time cycle for steel X10CrMoVNb9-1, 760 °C/2 h. For welding the materials TIG 141 process is used with parameters: 90 A and 10 V, with welding machine Cebora AC-DC 2540/T, and the prepared welded dissimilar metal welds are shown in Fig. 3.

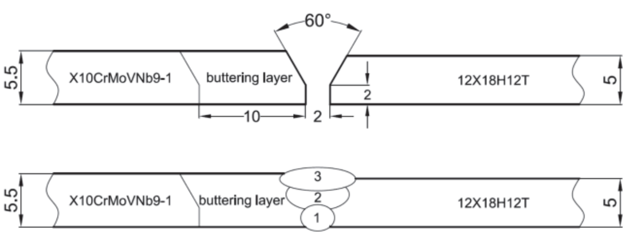


Figure 3 Experimental samples

The dissimilar metal welds were examined by radiographic control test to determine the weld quality of the samples. All welds were found to meet acceptance criteria of EN ISO 10675-1 [9].

4 RESEARCH METHODOLOGY

Mechanical properties of the dissimilar metal welds were determined with tensile test at room temperature according to EN ISO 6892-1[10] and Vickers hardness test according to ISO 6507-1[11] and ISO-9015-1 on arc welding joints [12]. Impact energy strength was not part of this research paper.

Part of the research methodology was the investigation of microstructure. Metallographic samples were made according to ISO 17639:2022 [13]. The same samples were used, first for metallography and for hardness test. For etching the base materials and weld metal Aqua regia (HNO_3 + 3HCl) mixed with glycerin was used. The microstructure was observed with an optical microscope (OM).

5 EXPERIMENTAL RESULTS

5.1 Tensile Testing

Tensile test was done according to EN ISO 4136:2022 [14] and EN ISO 6892-1 [10] for metallic materials with weld.

Figure 4 Tensile samples

In Fig. 4 are given the prepared samples for conducting the test. According to GOST 5632-72 the tensile strength range of the 12X18H12T steel is 539÷686 N/mm^2, and according to EN 10302-2008 of the X10CrMoVNb9-1 steel is min 620÷850 N/mm^2.

For dissimilar metal welds the acceptance criteria is the minimum tensile strength of the base material with a lower tensile strength. For this dissimilar metal weld is the 12X18H12T austenitic stainless steel. In Tab. 6 are given the results of the test, 3 test samples of each joint.

Table 6 Tensile test results

Sample No.	$R_{p0.2}$ / MPa	R_m / MPa	ε / %	Fracture
Sample 1.1	284.55	617	24.28	BM2
Sample 1.2	285	620	24.85	BM2
Sample 1.3	284.85	618	24.72	BM2
Sample 2.1	285	653	25	BM2
Sample 2.2	285.64	622	25.2	BM2
Sample 2.3	285.25	635	25.37	BM2

The performed tensile test showed that the obtained values meet the acceptance criterion and the place of fracture is the BM2, the austenitic stainless steel 12X18H12T, as shown in Fig. 5. The results indicated to a successful welding technology with no imperfections in the welded joints of these two heterogeneous materials and correctly selected welding filler material.

Figure 5 Tensile test fracture

5.2 Hardness Testing

The hardness measurement was performed on 30 locations (Fig. 6), using HV10 method.

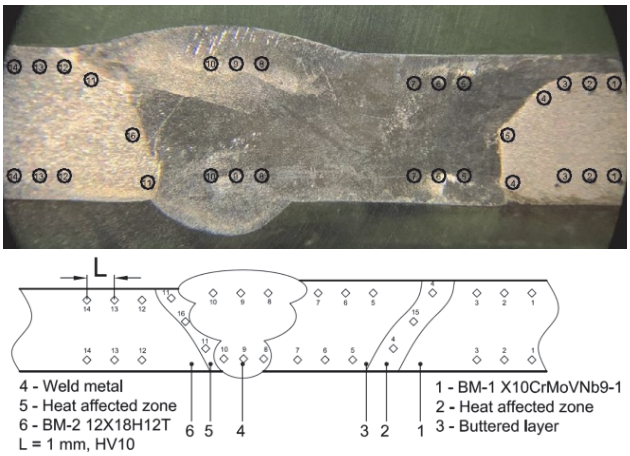


Figure 6 Hardness measurement points of sample 1

Measuring points are separated on lower and upper zone as shown in Fig. 6 with presented hardness measuring points on each dissimilar welded region: base materials, buttering layer of martensitic steel, HAZ regions and weld metal. The hardness distribution of the tested joints is given in Tab. 7 and Fig. 7.

The hardness values for X10CrMoVNb9-1 are within permissible range according to the standard ISO 15614-1 [15] for this type of steel and affiliations in steel group in HAZ < 350 HV. The hardness values for 12X18H12T are according to GOST 57423-2017, max. 186HV. BM1 has increased values considering the higher strength compared to BM2, and hardness values in HAZ were higher than in the base materials.

Table 7 Hardness measurements results of sample 1

BM1(X10CrMoVNb9-1)			HAZ1	BL		
Measuring points						
1	2	3	4	5	6	7
Lower zone						
209	224	221	224	160	168	157
Upper zone						
240	240	243	243	166	166	155
WM			HAZ2	BM2 (12X18H12T)		
Measuring points						
8	9	10	11	12	13	14
Lower zone						
151	142	145	143	128	134	131
Upper zone						
137	142	142	153	133	145	135
Middle zone						
15	16					
224	143					

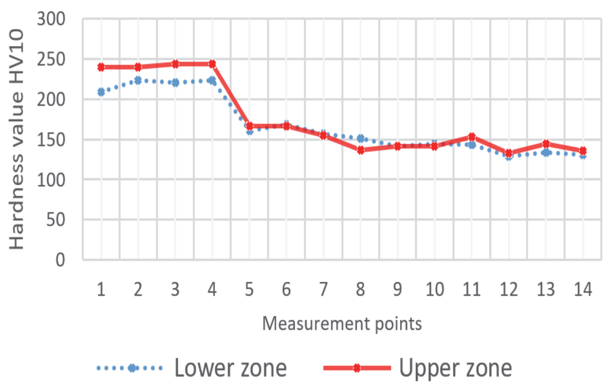
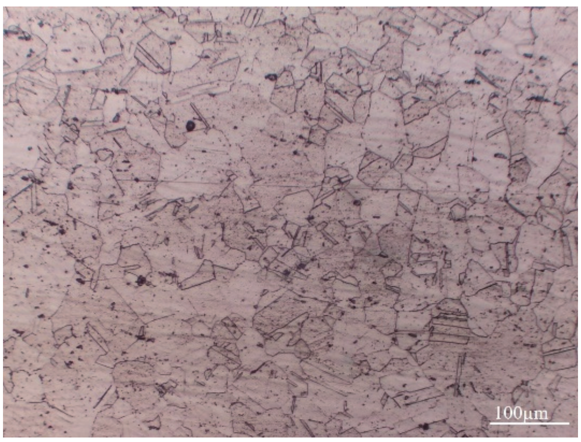


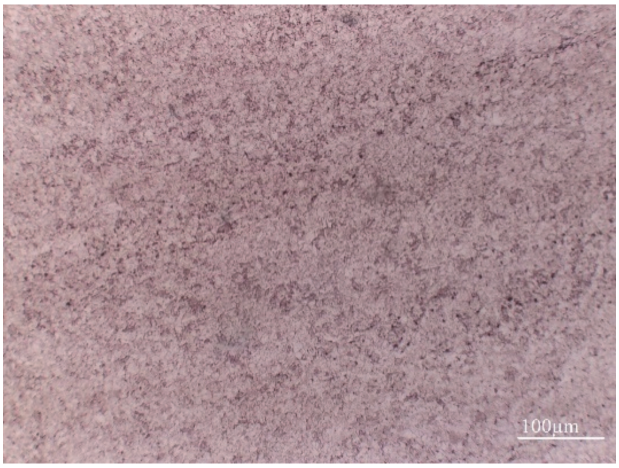
Figure 7 Hardness distribution across the welded dissimilar joint

5.3 Microstructure Analysis

Microstructure analysis is performed on a dissimilar metal weld in order to check for potential microstructural changes. The critical regions are the heat affected zone and fusion line region of martensitic steel and the weld metal. In Fig. 8a and b is shown the structure of base materials with magnification of 100×.



a) 12X18H12T



b) X10CrMoVNb9-1

Figure 8 Microstructure of base materials

The microstructure of 12X18H12T is presented in Fig. 8a; it is a structure with austenitic grains which provides high ductility, high strength and excellent creep resistance. In Fig. 8b is presented the microstructure of X10CrMoVNb9-1; it is a fine-grained structure with high strength, low ductility, and high creep resistance.

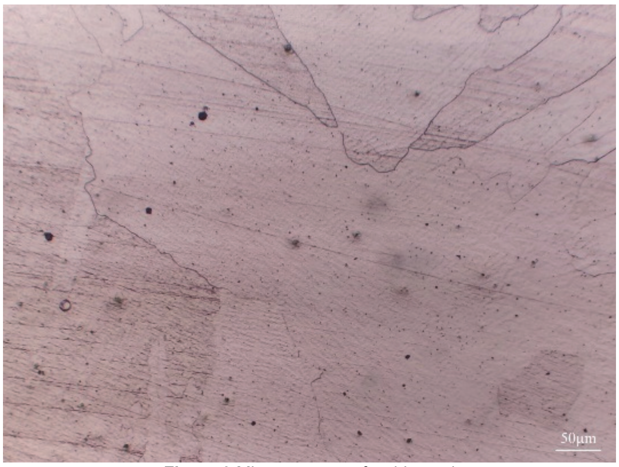


Figure 9 Microstructure of weld metal

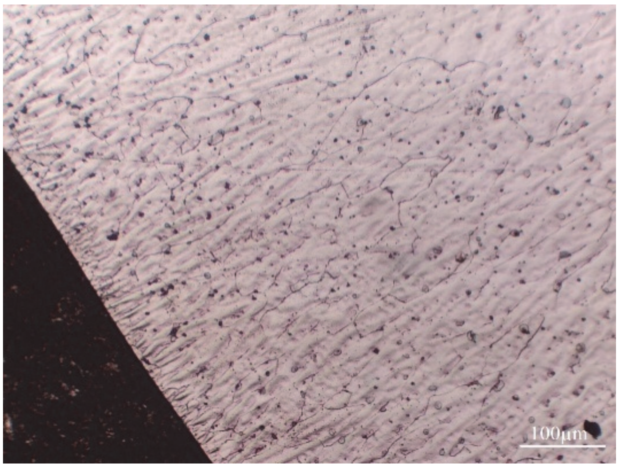


Figure 10 Microstructure of buttering layer of X10CrMoVNb9-1

The weld metal, Fig. 9, has austenitic structure without Cr carbide zone that becomes brittle in the martensitic weld deposit transition zone. In Fig. 10 is presented the microstructure of the martensitic weld deposit transition zone where buffer zone is created with nickel based additional material NiCr20Mn3Nb according to EN ISO 18274 (Thermanit Nicro 82). The buttering layer has an austenite structure with dendrite phase solidification.

This method is used for preventing the carbon diffusion from areas with lower content of Cr to area with higher content of Cr. The used materials differ in chemical compositions and welding of these two materials may occur with structural heterogeneities on the line of fusion of the welded joint or during the operation at elevated temperature.

Welding of martensitic steel, X10CrMoVNb9-1, and austenitic stainless steel, 12X18H12T, may result in occurrence of coarse-grained decarburized martensitic zone with low hardness of the line of fusion and hard carburized zone on the austenitic side. For preventing of creating hard carburized zone and carbon diffusion an additional nickel-based material is used to create a buffer zone since nickel is element where carbon does not diffuse into the nickel-base material.

6 CONCLUSION

In this study an experimental investigation of dissimilar weld metal between martensitic and austenitic steel was conducted with implementing buttering method of martensitic steel. For use of this type of joints in boiler industry several steps need to be implemented:

- buttering the enhanced martensitic steel with nickel electrode to prevent carbon diffusion in materials,
- performing preheating and PWHT of martensitic steel according to temperature time cycle of the material.

Dissimilar metal welds between X10CrMoNb9-1 and austenitic steels for high temperature applications are in demand in industrial applications and a lot of research work is made on martensitic steel and austenitic steels with consideration of creep properties and welding technology. The study of microstructure is important in these types of dissimilar metal welds because heterogeneity in the weld metal and heat affected zone are the reason for failure in service.

The radiography testing and tensile testing showed that the welds were made without any imperfection and meet the acceptance criteria according to the place of fracture, base material 2. The martensitic steel has higher strength values compared to austenitic steel and for that reason the fracture is expected on BM2.

The hardness values are within permissible range according to the appropriate standard for the type of materials and filler material documentation.

Microstructure analysis showed no cracks or imperfections on critical regions, as heat affected zone and weld metal. The weld metal is with austenitic structure and the buttering layer has an austenite structure with dendrite phase solidification.

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